

# 1

## The Microbial World and You

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The overall theme of this textbook is the relationship between microbes (very small organisms that usually require a microscope to be seen) and our lives. This relationship involves not only the familiar harmful effects of certain microorganisms, such as disease and food spoilage, but also their many beneficial effects. In this chapter we introduce you to some of the many ways microbes affect our lives. Microbes have been fruitful subjects of study for many years. We begin by introducing you to how organisms are named and classified, followed by a short history of microbiology that reveals how much we have learned in just a few hundred years. We then discuss the incredible diversity of microorganisms and their ecological importance, noting how they maintain balance in the environment by recycling chemical elements such as carbon and nitrogen among the soil, organisms, and the atmosphere. We also examine how microbes are used in commercial and industrial applications to produce foods, chemicals, and drugs (such as antibiotics); and to treat sewage, control pests, and clean up pollutants. We will discuss microbes as the cause of such diseases as avian (bird) flu, West Nile encephalitis, mad cow disease, diarrhea, hemorrhagic fever, and AIDS. We will also examine the growing public health problem of antibiotic-resistant bacteria. *Staphylococcus aureus* bacteria on human nasal epithelial cells are shown in the photograph. These bacteria live harmlessly on skin or inside the nose. Misuse of antibiotics allows the survival of bacteria with antibiotic-resistant genes such as methicillin-resistant *S. aureus* (MRSA). As illustrated in the Clinical Case, an infection caused by these bacteria is resistant to antibiotic treatment.

## Microbes in Our Lives

### LEARNING OBJECTIVE

**1-1** List several ways in which microbes affect our lives.

For many people, the words *germ* and *microbe* bring to mind a group of tiny creatures that do not quite fit into any of the categories in that old question, “Is it animal, vegetable, or mineral?”

**Microbes**, also called **microorganisms**, are minute living things that individually are usually too small to be seen with the unaided eye. The group includes bacteria (Chapter 11), fungi (yeasts and molds), protozoa, and microscopic algae (Chapter 12). It also includes viruses, those noncellular entities sometimes regarded as straddling the border between life and nonlife (Chapter 13). You will be introduced to each of these groups of microbes shortly.

We tend to associate these small organisms only with major diseases such as AIDS, uncomfortable infections, or such common inconveniences as spoiled food. However, the majority of microorganisms actually help maintain the balance of living organisms and chemicals in our environment. Marine and freshwater microorganisms form the basis of the food chain in oceans, lakes, and rivers. Soil microbes help break down wastes and incorporate nitrogen gas from the air into organic compounds, thereby recycling chemical elements between the soil, water, life, and air. Certain microbes play important roles in *photosynthesis*, a food- and oxygen-generating process that is critical to life on Earth. Humans and many other animals depend on the microbes in their intestines for digestion and the synthesis of some vitamins that their bodies require, including some B vitamins for metabolism and vitamin K for blood clotting.

Microorganisms also have many commercial applications. They are used in the synthesis of such chemical products as

vitamins, organic acids, enzymes, alcohols, and many drugs. For example, microbes are used to produce acetone and butanol, and the vitamins B<sub>2</sub> (riboflavin) and B<sub>12</sub> (cobalamin) are made biochemically. The process by which microbes produce acetone and butanol was discovered in 1914 by Chaim Weizmann, a Russian-born chemist working in England. With the outbreak of World War I in August of that year, the production of acetone became very important for making cordite (a smokeless form of gunpowder used in munitions). Weizmann's discovery played a significant role in determining the outcome of the war.

The food industry also uses microbes in producing, for example, vinegar, sauerkraut, pickles, soy sauce, cheese, yogurt, bread, and alcoholic beverages. In addition, enzymes from microbes can now be manipulated to cause the microbes to produce substances they normally do not synthesize, including cellulose, digestive aids, and drain cleaner, plus important therapeutic substances such as insulin. Microbial enzymes may even have helped produce your favorite pair of jeans (see the box on page 3).

Though only a minority of microorganisms are **pathogenic** (disease-producing), practical knowledge of microbes is necessary for medicine and the related health sciences. For example, hospital workers must be able to protect patients from common microbes that are normally harmless but pose a threat to the sick and injured.

Today we understand that microorganisms are found almost everywhere. Yet not long ago, before the invention of the microscope, microbes were unknown to scientists. Thousands of people died in devastating epidemics, the causes of which were not understood. Entire families died because vaccinations and antibiotics were not available to fight infections.

We can get an idea of how our current concepts of microbiology developed by looking at a few historic milestones in microbiology that have changed our lives. First, however, we will look at the major groups of microbes and how they are named and classified.

### CHECK YOUR UNDERSTANDING

- ✓ Describe some of the destructive and beneficial actions of microbes. **1-1\***

## Naming and Classifying Microorganisms

### LEARNING OBJECTIVES

- 1-2** Recognize the system of scientific nomenclature that uses two names: a genus and a specific epithet.
- 1-3** Differentiate the major characteristics of each group of microorganisms.
- 1-4** List the three domains.

\* The numbers following Check Your Understanding questions refer to the corresponding Learning Objectives.

### Clinical Case: A Simple Spider Bite?

Andrea is a normally healthy 22-year-old college student who lives at home with her mother and younger sister, a high school gymnast. She is trying to work on a paper for her psychology class but is having a hard time because a red, swollen sore on her right wrist is making typing difficult. “Why won’t this spider bite heal?” she wonders. “It’s been there for days!” She makes an appointment with her doctor so she can show him the painful lesion. Although Andrea does not have a fever, she does have an elevated white blood cell count that indicates a bacterial infection. Andrea’s doctor suspects that this isn’t a spider bite at all, but a staph infection. He prescribes a  $\beta$ -lactam antibiotic, cephalosporin. Learn more about the development of Andrea’s illness on the following pages.

**What is staph? Read on to find out.**

2 17 19 20 21



## Designer Jeans: Made by Microbes?

**Denim blue jeans have become increasingly popular** ever since Levi Strauss and Jacob Davis first made them for California gold miners in 1873. Now, companies that manufacture blue jeans are turning to microbiology to develop environmentally sound production methods that minimize toxic wastes and the associated costs.

### Stone Washing?

A softer denim, called “stone-washed,” was introduced in the 1980s. Enzymes, called cellulases, from *Trichoderma* fungus are used to digest some of the cellulose in the cotton, thereby softening it and giving the stone-washed appearance. Unlike many chemical reactions, enzymes usually operate at safe temperatures and pH. Moreover, enzymes are proteins, so they are readily degraded for removal from wastewater.

### Fabric

Cotton production requires large tracts of land, pesticides, and fertilizer, and the crop yield depends on the weather. However, bacteria can produce both cotton and polyester with less environmental impact. *Gluconacetobacter xylinus* bacteria make cellulose by attaching glucose units to simple chains in the outer membrane of the bacterial cell wall. The cellulose microfibrils are extruded through pores in the outer

membrane, and bundles of microfibrils then twist into ribbons.

### Bleaching

Peroxide is a safer bleaching agent than chlorine and can be easily removed from fabric and wastewater by enzymes. Researchers at Novo Nordisk Biotech cloned a mushroom peroxidase gene in yeast and grew the yeasts in washing machine conditions. The yeast that survived the washing machine were selected as the peroxidase producers.

### Indigo

Chemical synthesis of indigo requires a high pH and produces waste that explodes in contact with air. However, a California biotechnology company, Genencor, has developed a method to produce indigo by using bacteria. Researchers identified a gene from a soil bacterium, *Pseudomonas putida*, for conversion of the bacterial by-product indole to indigo. This gene was put into *Escherichia coli* bacteria, which then turned blue.

### Bioplastic

Microbes can even make plastic zippers and packaging

material for the jeans. Over 25 bacteria make polyhydroxyalkanoate (PHA) inclusion granules as a food reserve. PHAs are similar to common plastics, and because they are made by bacteria, they are also readily degraded by many bacteria. PHAs could provide a biodegradable alternative to conventional plastic, which is made from petroleum.



*E. coli* bacteria produce indigo from tryptophan.



Indigo-producing *E. coli* bacteria.

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TEM

## Nomenclature

The system of nomenclature (naming) for organisms in use today was established in 1735 by Carolus Linnaeus. Scientific names are latinized because Latin was the language traditionally used by scholars. Scientific nomenclature assigns each organism two names—the **genus** (plural: *genera*) is the first name and is always capitalized; the **specific epithet** (*species* name) follows and is not capitalized. The organism is referred to by both the genus and the specific epithet, and both names are underlined or italicized. By custom, after a scientific name has been mentioned once, it can be abbreviated with the initial of the genus followed by the specific epithet.

Scientific names can, among other things, describe an organism, honor a researcher, or identify the habitat of a species. For example, consider *Staphylococcus aureus* (staf-i-lō-kok'kus ō'rē-us), a bacterium commonly found on human skin. *Staphylo-* describes the clustered arrangement of the cells; *coccus* indicates that they

are shaped like spheres. The specific epithet, *aureus*, is Latin for golden, the color of many colonies of this bacterium. The genus of the bacterium *Escherichia coli* (esh-ĕ-rik'-ĕ-ā kō'li or kō'lē) is named for a scientist, Theodor Escherich, whereas its specific epithet, *coli*, reminds us that *E. coli* live in the colon, or large intestine. **Table 1.1** contains more examples.

### CHECK YOUR UNDERSTANDING

✓ Distinguish a genus from a specific epithet. **1-2**

## Types of Microorganisms

The classification and identification of microorganisms is discussed in Chapter 10. Here is an overview of the major groups.

### Bacteria

**Bacteria** (singular: **bacterium**) are relatively simple, single-celled (unicellular) organisms. Because their genetic material is not

**TABLE 1.1 Making Scientific Names Familiar**

Use the word roots guide in Appendix E to find out what the name means. The name will not seem so strange if you translate it. When you encounter a new name, practice saying it out loud. The exact pronunciation is not as important as the familiarity you will gain. Guidelines for pronunciation are given in Appendix D.

Following are some examples of microbial names you may encounter in the popular press as well as in the lab.

	Pronunciation	Source of Genus Name	Source of Specific Epithet
<i>Salmonella enterica</i> (bacterium)	sal-mōn-el'lä en-ter'i-kä	Honors public health microbiologist Daniel Salmon	Found in the intestines ( <i>entero</i> -)
<i>Streptococcus pyogenes</i> (bacterium)	strep-tō-kok'kus pl-āj'en-ēz	Appearance of cells in chains ( <i>strepto</i> -)	Forms pus ( <i>pyo</i> -)
<i>Saccharomyces cerevisiae</i> (yeast)	sak-ä-rō-mī'ses se-ri-vis'ē-tī	Fungus ( <i>-myces</i> ) that uses sugar ( <i>saccharo</i> -)	Makes beer ( <i>cerevisia</i> )
<i>Penicillium chrysogenum</i> (fungus)	pen-i-sil'lē-um krī-so'jen-um	Tuftlike or paintbrush ( <i>penicill</i> -) appearance microscopically	Produces a yellow ( <i>chryso</i> -) pigment
<i>Trypanosoma cruzi</i> (protozoan)	tri-pa-nō-sō'mä krüz'ē	Corkscrew- ( <i>trypano</i> -, borer; <i>soma</i> -, body)	Honors epidemiologist Oswaldo Cruz

enclosed in a special nuclear membrane, bacterial cells are called **prokaryotes** (prō-kar'e-ōts), from Greek words meaning prenucleus. Prokaryotes include both bacteria and archaea.

Bacterial cells generally appear in one of several shapes. *Bacillus* (bā-sil'lus) (rodlike), illustrated in **Figure 1.1a**, *coccus* (kok'kus) (spherical or ovoid), and *spiral* (corkscrew or curved) are among the most common shapes, but some bacteria are star-shaped or square (see Figures 4.1 through 4.5, pages 77–78). Individual bacteria may form pairs, chains, clusters, or other groupings; such formations are usually characteristic of a particular genus or species of bacteria.

Bacteria are enclosed in cell walls that are largely composed of a carbohydrate and protein complex called *peptidoglycan*. (By contrast, cellulose is the main substance of plant and algal cell walls.) Bacteria generally reproduce by dividing into two equal cells; this process is called *binary fission*. For nutrition, most bacteria use organic chemicals, which in nature can be derived from either dead or living organisms. Some bacteria can manufacture their own food by photosynthesis, and some can derive nutrition from inorganic substances. Many bacteria can “swim” by using moving appendages called *flagella*. (For a complete discussion of bacteria, see Chapter 11.)

## Archaea

Like bacteria, **archaea** (är'kē-ä) consist of prokaryotic cells, but if they have cell walls, the walls lack peptidoglycan. Archaea, often found in extreme environments, are divided into three main groups. The *methanogens* produce methane as a waste product from respiration. The *extreme halophiles* (*halo* = salt; *philic* = loving) live in extremely salty environments such as the Great Salt Lake and the Dead Sea. The *extreme thermophiles*

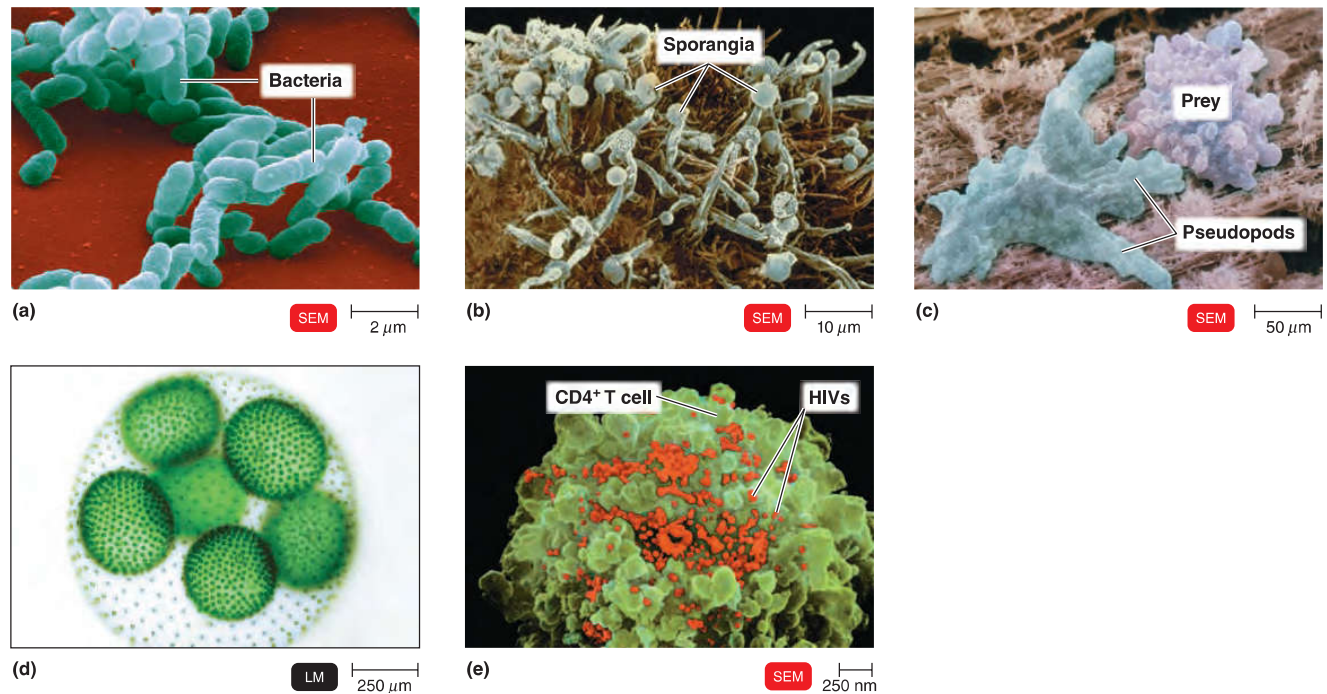
(*therm* = heat) live in hot sulfurous water, such as hot springs at Yellowstone National Park. Archaea are not known to cause disease in humans.

## Fungi

**Fungi** (singular: **fungus**) are **eukaryotes** (yū-kar'ē-ōts), organisms whose cells have a distinct nucleus containing the cell's genetic material (DNA), surrounded by a special envelope called the nuclear membrane. Organisms in the Kingdom Fungi may be unicellular or multicellular (see Chapter 12, page 331). Large multicellular fungi, such as mushrooms, may look somewhat like plants, but unlike most plants, fungi cannot carry out photosynthesis. True fungi have cell walls composed primarily of a substance called *chitin*. The unicellular forms of fungi, *yeasts*, are oval microorganisms that are larger than bacteria. The most typical fungi are *molds* (**Figure 1.1b**). Molds form visible masses called *mycelia*, which are composed of long filaments (*hyphae*) that branch and intertwine. The cottony growths sometimes found on bread and fruit are mold mycelia. Fungi can reproduce sexually or asexually. They obtain nourishment by absorbing solutions of organic material from their environment—whether soil, seawater, freshwater, or an animal or plant host. Organisms called *slime molds* have characteristics of both fungi and amoebas. They are discussed in detail in Chapter 12.

## Protozoa

**Protozoa** (singular: **protozoan**) are unicellular eukaryotic microbes (see Chapter 12, page 348). Protozoa move by pseudopods, flagella, or cilia. Amebae (**Figure 1.1c**) move by using extensions of their cytoplasm called *pseudopods* (false feet). Other protozoa have long *flagella* or numerous shorter appendages for locomotion



**Figure 1.1** Types of microorganisms.

**NOTE:** Throughout the book, a red icon under a micrograph indicates that the micrograph has been artificially colored. (a) The rod-shaped bacterium *Haemophilus influenzae*, one of the bacterial causes of pneumonia. (b) *Mucor*, a

common bread mold, is a type of fungus. When released from sporangia, spores that land on a favorable surface germinate into a network of hyphae (filaments) that absorb nutrients. (c) An amoeba, a protozoan, approaching a food particle. (d) The pond alga *Volvox*. (e) Several human

immunodeficiency viruses (HIVs), the causative agent of AIDS, budding from a CD4<sup>+</sup> T cell.

**Q** How are bacteria, archaea, fungi, protozoa, algae, and viruses distinguished on the basis of cellular structure?

called *cilia*. Protozoa have a variety of shapes and live either as free entities or as *parasites* (organisms that derive nutrients from living hosts) that absorb or ingest organic compounds from their environment. Some protozoa, such as *Euglena*, are photosynthetic. They use light as a source of energy and carbon dioxide as their chief source of carbon to produce sugars. Protozoa can reproduce sexually or asexually.

### Algae

**Algae** (singular: **alga**) are photosynthetic eukaryotes with a wide variety of shapes and both sexual and asexual reproductive forms (Figure 1.1d). The algae of interest to microbiologists are usually unicellular (see Chapter 12, page 343). The cell walls of many algae are composed of a carbohydrate called *cellulose*. Algae are abundant in freshwater and salt water, in soil, and in association with plants. As photosynthesizers, algae need light, water, and carbon dioxide for food production and growth, but they do not generally require organic compounds from the environment. As a result of photosynthesis, algae produce oxygen and carbohydrates that are then utilized by other organisms, including animals. Thus, they play an important role in the balance of nature.

### Viruses

**Viruses** (Figure 1.1e) are very different from the other microbial groups mentioned here. They are so small that most can be seen only with an electron microscope, and they are acellular (not cellular). Structurally very simple, a virus particle contains a core made of only one type of nucleic acid, either DNA or RNA. This core is surrounded by a protein coat, which is sometimes encased by a lipid membrane called an envelope. All living cells have RNA *and* DNA, can carry out chemical reactions, and can reproduce as self-sufficient units. Viruses can reproduce only by using the cellular machinery of other organisms. Thus, on the one hand, viruses are considered to be living only when they multiply within host cells they infect. In this sense, viruses are parasites of other forms of life. On the other hand, viruses are not considered to be living because they are inert outside living hosts. (Viruses will be discussed in detail in Chapter 13.)

### Multicellular Animal Parasites

Although multicellular animal parasites are not strictly microorganisms, they are of medical importance and therefore will be



discussed in this text. Animal parasites are eukaryotes. The two major groups of parasitic worms are the flatworms and the roundworms, collectively called **helminths** (see Chapter 12, page 354). During some stages of their life cycle, helminths are microscopic in size. Laboratory identification of these organisms includes many of the same techniques used for identifying microbes.

### CHECK YOUR UNDERSTANDING

- ✓ Which groups of microbes are prokaryotes? Which are eukaryotes? **1-3**

## Classification of Microorganisms

Before the existence of microbes was known, all organisms were grouped into either the animal kingdom or the plant kingdom. When microscopic organisms with characteristics of animals and plants were discovered late in the seventeenth century, a new system of classification was needed. Still, biologists could not agree on the criteria for classifying these new organisms until the late 1970s.

In 1978, Carl Woese devised a system of classification based on the cellular organization of organisms. It groups all organisms in three domains as follows:

1. Bacteria (cell walls contain a protein–carbohydrate complex called peptidoglycan)
2. Archaea (cell walls, if present, lack peptidoglycan)
3. Eukarya, which includes the following:
  - Protists (slime molds, protozoa, and algae)
  - Fungi (unicellular yeasts, multicellular molds, and mushrooms)
  - Plants (mosses, ferns, conifers, and flowering plants)
  - Animals (sponges, worms, insects, and vertebrates)

Classification will be discussed in more detail in Chapters 10 through 12.

### CHECK YOUR UNDERSTANDING

- ✓ What are the three domains? **1-4**

## A Brief History of Microbiology

### LEARNING OBJECTIVES

- 1-5** Explain the importance of observations made by Hooke and van Leeuwenhoek.
- 1-6** Compare spontaneous generation and biogenesis.
- 1-7** Identify the contributions to microbiology made by Needham, Spallanzani, Virchow, and Pasteur.
- 1-8** Explain how Pasteur's work influenced Lister and Koch.
- 1-9** Identify the importance of Koch's postulates.
- 1-10** Identify the importance of Jenner's work.
- 1-11** Identify the contributions to microbiology made by Ehrlich and Fleming.

- 1-12** Define *bacteriology*, *mycology*, *parasitology*, *immunology*, and *virology*.

- 1-13** Explain the importance of microbial genetics and molecular biology.

The science of microbiology dates back only 200 years, yet the recent discovery of *Mycobacterium tuberculosis* (mī-kō-bak-ti'rē-um tū-bēr-ku-lō'sis) DNA in 3000-year-old Egyptian mummies reminds us that microorganisms have been around for much longer. In fact, bacterial ancestors were the first living cells to appear on Earth. Although we know relatively little about what earlier people thought about the causes, transmission, and treatment of disease, we know more about the history of the past few hundred years. Let's look now at some key developments in microbiology that have spurred the field to its current technological state.

## The First Observations

One of the most important discoveries in biology occurred in 1665. After observing a thin slice of cork through a relatively crude microscope, an Englishman, Robert Hooke, reported to the world that life's smallest structural units were "little boxes," or "cells," as he called them. Using his improved version of a compound microscope (one that uses two sets of lenses), Hooke was able to see individual cells. Hooke's discovery marked the beginning of the **cell theory**—the theory that *all living things are composed of cells*. Subsequent investigations into the structure and function of cells were based on this theory.

Though Hooke's microscope was capable of showing large cells, it lacked the resolution that would have allowed him to see microbes clearly. The Dutch merchant and amateur scientist Anton van Leeuwenhoek was probably the first actually to observe live microorganisms through the magnifying lenses of more than 400 microscopes he constructed. Between 1673 and 1723, he wrote a series of letters to the Royal Society of London describing the "animalcules" he saw through his simple, single-lens microscope. Van Leeuwenhoek made detailed drawings of "animalcules" he found in rainwater, in his own feces, and in material scraped from his teeth. These drawings have since been identified as representations of bacteria and protozoa (**Figure 1.2**).

### CHECK YOUR UNDERSTANDING

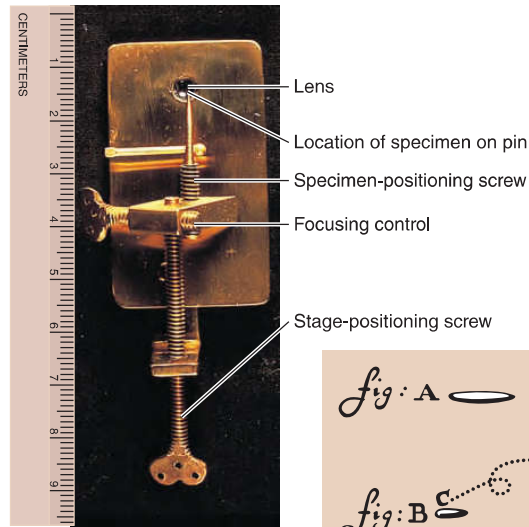
- ✓ What is the cell theory? **1-5**

## The Debate over Spontaneous Generation

After van Leeuwenhoek discovered the previously "invisible" world of microorganisms, the scientific community of the time became interested in the origins of these tiny living things. Until the second half of the nineteenth century, many scientists and philosophers believed that some forms of life could arise spontaneously from nonliving matter; they called this hypothetical process **spontaneous generation**. Not much more than 100 years ago, people commonly believed that toads, snakes, and mice could be born of moist soil; that flies could emerge from manure;



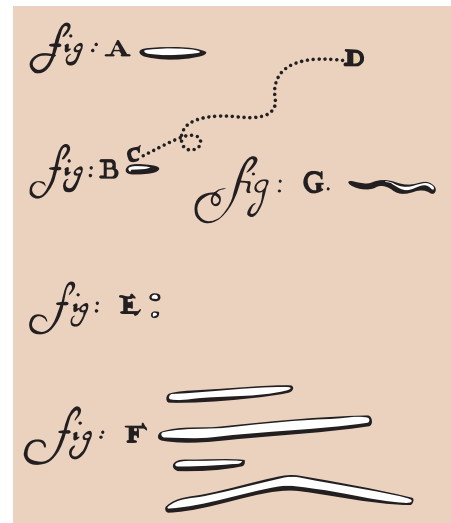
(a) Van Leeuwenhoek using his microscope



(b) Microscope replica

**Figure 1.2 Anton van Leeuwenhoek's microscopic observations.** (a) By holding his brass microscope toward a source of light, van Leeuwenhoek was able to observe living organisms too small to be seen with the unaided eye. (b) The specimen was placed on the tip of the adjustable point and viewed from the other side through the tiny, nearly spherical lens. The highest magnification possible with his microscopes was about 300 $\times$  (times). (c) Some of van Leeuwenhoek's drawings of bacteria, made in 1683. The letters represent various shapes of bacteria. C–D represents a path of motion he observed.

**Q** Why was van Leeuwenhoek's discovery so important?



(c) Drawings of bacteria

and that maggots (which we now know are the larvae of flies) could arise from decaying corpses.

### Evidence Pro and Con

A strong opponent of spontaneous generation, the Italian physician Francesco Redi set out in 1668 to demonstrate that maggots did not arise spontaneously from decaying meat. Redi filled two jars with decaying meat. The first was left unsealed; the flies laid their eggs on the meat, and the eggs developed into larvae. The second jar was sealed, and because the flies could not lay their eggs on the meat, no maggots appeared. Still, Redi's antagonists were not convinced; they claimed that fresh air was needed for spontaneous generation. So Redi set up a second experiment, in which he covered a jar with a fine net instead of sealing it. No larvae appeared in the gauze-covered jar, even though air was present. Maggots appeared only when flies were allowed to leave their eggs on the meat.

Redi's results were a serious blow to the long-held belief that large forms of life could arise from nonlife. However, many scientists still believed that small organisms, such as

van Leeuwenhoek's "animalcules," were simple enough to be generated from nonliving materials.

The case for spontaneous generation of microorganisms seemed to be strengthened in 1745, when John Needham, an Englishman, found that even after he heated nutrient fluids (chicken broth and corn broth) before pouring them into covered flasks, the cooled solutions were soon teeming with microorganisms. Needham claimed that microbes developed spontaneously from the fluids. Twenty years later, Lazzaro Spallanzani, an Italian scientist, suggested that microorganisms from the air probably had entered Needham's solutions after they were boiled. Spallanzani showed that nutrient fluids heated *after* being sealed in a flask did not develop microbial growth. Needham responded by claiming the "vital force" necessary for spontaneous generation had been destroyed by the heat and was kept out of the flasks by the seals.

This intangible "vital force" was given all the more credence shortly after Spallanzani's experiment, when Anton Laurent Lavoisier showed the importance of oxygen to life. Spallanzani's observations were criticized on the grounds that there was not enough oxygen in the sealed flasks to support microbial life.

## The Theory of Biogenesis

The issue was still unresolved in 1858, when the German scientist Rudolf Virchow challenged the case for spontaneous generation with the concept of **biogenesis**, the claim that living cells can arise only from preexisting living cells. Because he could offer no scientific proof, arguments about spontaneous generation continued until 1861, when the issue was finally resolved by the French scientist Louis Pasteur.

With a series of ingenious and persuasive experiments, Pasteur demonstrated that microorganisms are present in the air and can contaminate sterile solutions, but that air itself does not create microbes. He filled several short-necked flasks with beef broth and then boiled their contents. Some were then left open and allowed to cool. In a few days, these flasks were found to be contaminated with microbes. The other flasks, sealed after boiling, were free of microorganisms. From these results, Pasteur reasoned that microbes in the air were the agents responsible for contaminating nonliving matter.

Pasteur next placed broth in open-ended, long-necked flasks and bent the necks into S-shaped curves (**Figure 1.3**). The contents of these flasks were then boiled and cooled. The broth in the flasks did not decay and showed no signs of life, even after months. Pasteur's unique design allowed air to pass into the flask, but the curved neck trapped any airborne microorganisms that might contaminate the broth. (Some of these original vessels are still on display at the Pasteur Institute in Paris. They have been sealed but, like the flask shown in **Figure 1.3**, show no sign of contamination more than 100 years later.)

Pasteur showed that microorganisms can be present in nonliving matter—on solids, in liquids, and in the air. Furthermore, he demonstrated conclusively that microbial life can be destroyed by heat and that methods can be devised to block the access of airborne microorganisms to nutrient environments. These discoveries form the basis of **aseptic techniques**, techniques that prevent contamination by unwanted microorganisms, which are now the standard practice in laboratory and many medical procedures. Modern aseptic techniques are among the first and most important concepts that a beginning microbiologist learns.

Pasteur's work provided evidence that microorganisms cannot originate from mystical forces present in nonliving materials. Rather, any appearance of “spontaneous” life in nonliving solutions can be attributed to microorganisms that were already present in the air or in the fluids themselves. Scientists now believe that a form of spontaneous generation probably did occur on the primitive Earth when life first began, but they agree that this does not happen under today's environmental conditions.

## CHECK YOUR UNDERSTANDING

- What evidence supported spontaneous generation? **1-6**
- How was spontaneous generation disproved? **1-7**

## The Golden Age of Microbiology

The work that began with Pasteur started an explosion of discoveries in microbiology. The period from 1857 to 1914 has been appropriately named the Golden Age of Microbiology. During this period, rapid advances, spearheaded mainly by Pasteur and Robert Koch, led to the establishment of microbiology as a science. Discoveries during these years included both the agents of many diseases and the role of immunity in preventing and curing disease. During this productive period, microbiologists studied the chemical activities of microorganisms, improved the techniques for performing microscopy and culturing microorganisms, and developed vaccines and surgical techniques. Some of the major events that occurred during the Golden Age of Microbiology are listed in **Figure 1.4**.

## Fermentation and Pasteurization

One of the key steps that established the relationship between microorganisms and disease occurred when a group of French merchants asked Pasteur to find out why wine and beer soured. They hoped to develop a method that would prevent spoilage when those beverages were shipped long distances. At the time, many scientists believed that air converted the sugars in these fluids into alcohol. Pasteur found instead that microorganisms called yeasts convert the sugars to alcohol in the absence of air. This process, called **fermentation** (see Chapter 5, page 130), is used to make wine and beer. Souring and spoilage are caused by different microorganisms called bacteria. In the presence of air, bacteria change the alcohol into vinegar (acetic acid).

Pasteur's solution to the spoilage problem was to heat the beer and wine just enough to kill most of the bacteria that caused the spoilage. The process, called **pasteurization**, is now commonly used to reduce spoilage and kill potentially harmful bacteria in milk as well as in some alcoholic drinks. Showing the connection between food spoilage and microorganisms was a major step toward establishing the relationship between disease and microbes.

## The Germ Theory of Disease

As we have seen, the fact that many kinds of diseases are related to microorganisms was unknown until relatively recently. Before the time of Pasteur, effective treatments for many diseases were discovered by trial and error, but the causes of the diseases were unknown.

The realization that yeasts play a crucial role in fermentation was the first link between the activity of a microorganism and physical and chemical changes in organic materials. This discovery alerted scientists to the possibility that microorganisms might have similar relationships with plants and animals—specifically, that microorganisms might cause disease. This idea was known as the **germ theory of disease**.

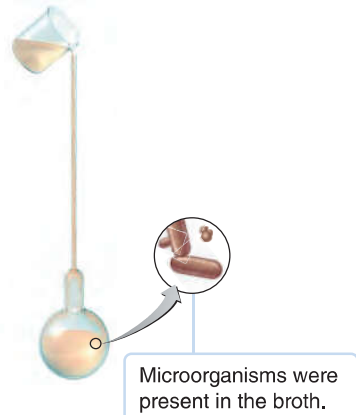


## FOUNDATION FIGURE 1.3

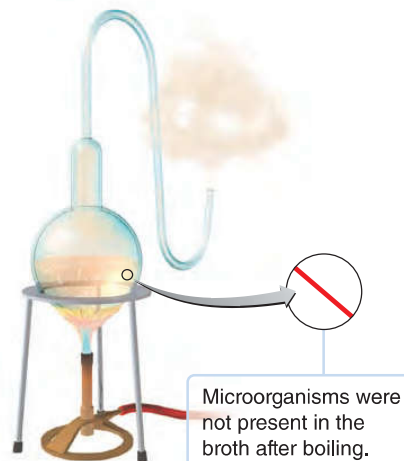
# Disproving the Theory of Spontaneous Generation

According to the theory of spontaneous generation, life can arise spontaneously from nonliving matter, such as dead corpses and soil. Pasteur's experiment, described below, demonstrated that microbes are present in nonliving matter—air, liquids, and solids.

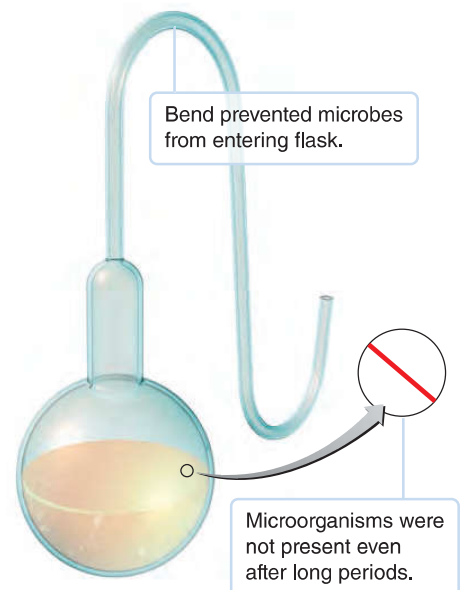
- 1 Pasteur first poured beef broth into a long-necked flask.



- 2 Next he heated the neck of the flask and bent it into an S-shape; then he boiled the broth for several minutes.



- 3 Microorganisms did not appear in the cooled solution, even after long periods.



### KEY CONCEPTS

- Pasteur demonstrated that microbes are responsible for food spoilage, leading researchers to the connection between microbes and disease.
- His experiments and observations provided the basis of aseptic techniques, which are used to prevent microbial contamination, as shown in the photo at right.

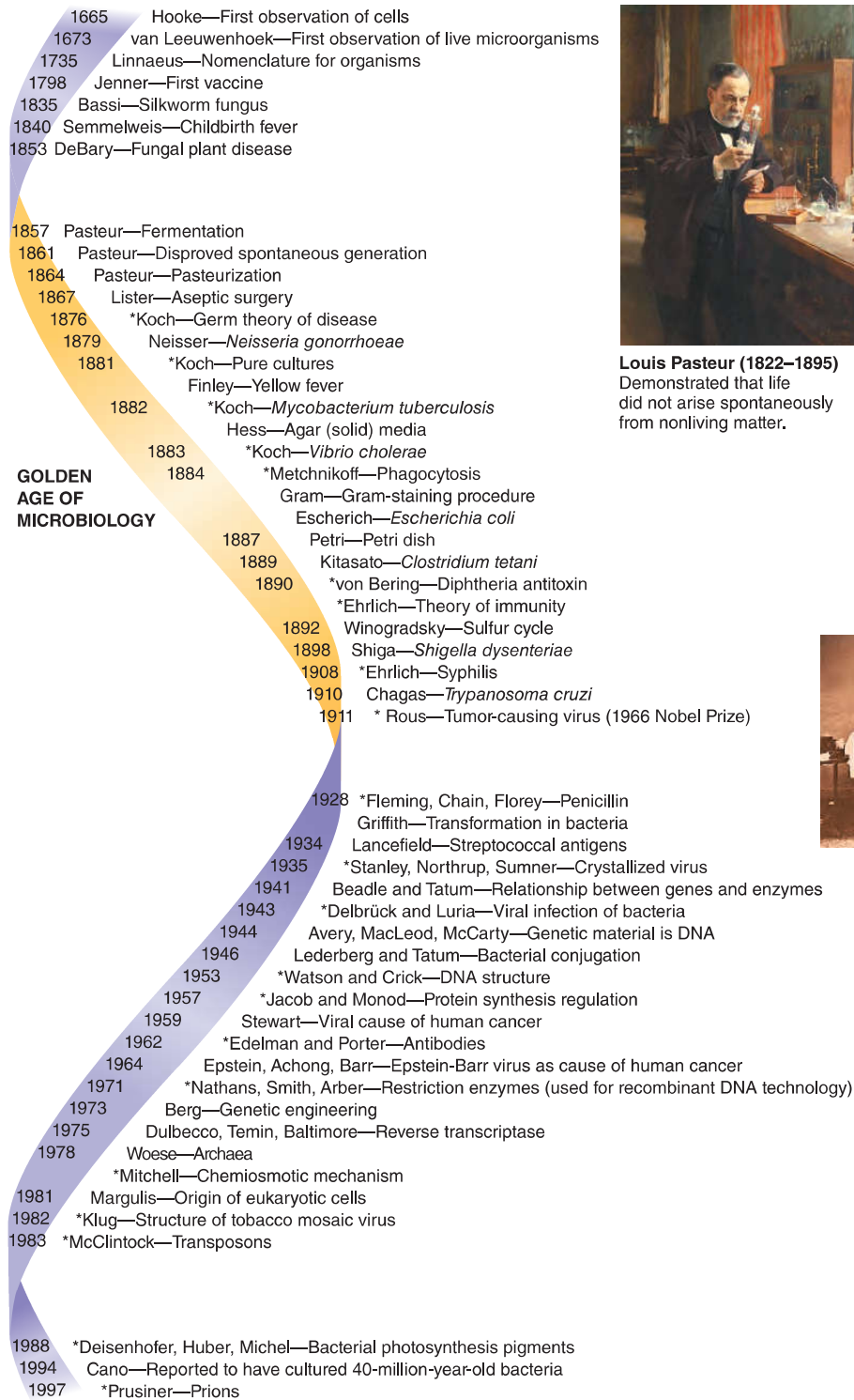


The germ theory was a difficult concept for many people to accept at that time because for centuries disease was believed to be punishment for an individual's crimes or misdeeds. When the inhabitants of an entire village became ill, people often blamed the disease on demons appearing as foul odors from sewage or on poisonous vapors from swamps. Most people born in Pasteur's time found it inconceivable that "invisible" microbes could travel through the air to infect plants and animals or remain on clothing and bedding to be transmitted from one person to another. Despite these doubts scientists gradually accumulated the information needed to support the new germ theory.

In 1865, Pasteur was called upon to help fight silkworm disease, which was ruining the silk industry throughout Europe.

Years earlier, in 1835, Agostino Bassi, an amateur microscopist, had proved that another silkworm disease was caused by a fungus. Using data provided by Bassi, Pasteur found that the more recent infection was caused by a protozoan, and he developed a method for recognizing afflicted silkworm moths.

In the 1860s, Joseph Lister, an English surgeon, applied the germ theory to medical procedures. Lister was aware that in the 1840s, the Hungarian physician Ignaz Semmelweis had demonstrated that physicians, who at the time did not disinfect their hands, routinely transmitted infections (puerperal, or child-birth, fever) from one obstetrical patient to another. Lister had also heard of Pasteur's work connecting microbes to animal diseases. Disinfectants were not used at the time, but Lister knew



**Louis Pasteur (1822–1895)**  
Demonstrated that life did not arise spontaneously from nonliving matter.



**Robert Koch (1843–1910)**  
Established experimental steps for directly linking a specific microbe to a specific disease.



**Joseph Lister (1827–1912)**  
Performed surgery under antiseptic conditions using phenol. Proved that microbes caused surgical wound infections.



**Rebecca C. Lancefield (1895–1981)**  
Classified streptococci according to serotypes (variants within a species)

**Figure 1.4** Milestones in microbiology, highlighting those that occurred during the Golden Age of Microbiology. An asterisk (\*) indicates a Nobel laureate.

**Q** Why do you think the Golden Age of Microbiology occurred when it did?

that phenol (carbolic acid) kills bacteria, so he began treating surgical wounds with a phenol solution. The practice so reduced the incidence of infections and deaths that other surgeons quickly adopted it. Lister's technique was one of the earliest medical attempts to control infections caused by microorganisms. In fact, his findings proved that microorganisms cause surgical wound infections.

The first proof that bacteria actually cause disease came from Robert Koch in 1876. Koch, a German physician, was Pasteur's young rival in the race to discover the cause of anthrax, a disease that was destroying cattle and sheep in Europe. Koch discovered rod-shaped bacteria now known as *Bacillus anthracis* (bă-sil'lus an-thră'sis) in the blood of cattle that had died of anthrax. He cultured the bacteria on nutrients and then injected samples of the culture into healthy animals. When these animals became sick and died, Koch isolated the bacteria in their blood and compared them with the originally isolated bacteria. He found that the two sets of blood cultures contained the same bacteria.

Koch thus established **Koch's postulates**, a sequence of experimental steps for directly relating a specific microbe to a specific disease (see Figure 14.3, page 407). During the past 100 years, these same criteria have been invaluable in investigations proving that specific microorganisms cause many diseases. Koch's postulates, their limitations, and their application to disease will be discussed in greater detail in Chapter 14.

## Vaccination

Often a treatment or preventive procedure is developed before scientists know why it works. The smallpox vaccine is an example. On May 4, 1796, almost 70 years before Koch established that a specific microorganism causes anthrax, Edward Jenner, a young British physician, embarked on an experiment to find a way to protect people from smallpox.

Smallpox epidemics were greatly feared. The disease periodically swept through Europe, killing thousands, and it wiped out 90% of the American Indians on the East Coast when European settlers first brought the infection to the New World.

When a young milkmaid informed Jenner that she couldn't get smallpox because she already had been sick from cowpox—a much milder disease—he decided to put the girl's story to the test. First Jenner collected scrapings from cowpox blisters. Then he inoculated a healthy 8-year-old volunteer with the cowpox material by scratching the person's arm with a pox-contaminated needle. The scratch turned into a raised bump. In a few days, the volunteer became mildly sick but recovered and never again contracted either cowpox or smallpox. The process was called *vaccination*, from the Latin word *vacca*, meaning cow. Pasteur gave it this name in honor of Jenner's work. The protection from disease provided by vaccination (or by recovery from the disease

itself) is called **immunity**. We will discuss the mechanisms of immunity in Chapter 17.

Years after Jenner's experiment, in about 1880, Pasteur discovered why vaccinations work. He found that the bacterium that causes fowl cholera lost its ability to cause disease (lost its *virulence*, or became *avirulent*) after it was grown in the laboratory for long periods. However, it—and other microorganisms with decreased virulence—was able to induce immunity against subsequent infections by its virulent counterparts. The discovery of this phenomenon provided a clue to Jenner's successful experiment with cowpox. Both cowpox and smallpox are caused by viruses. Even though cowpox virus is not a laboratory-produced derivative of smallpox virus, it is so closely related to the smallpox virus that it can induce immunity to both viruses. Pasteur used the term *vaccine* for cultures of avirulent microorganisms used for preventive inoculation.

Jenner's experiment marked the first time in a Western culture that a living viral agent—the cowpox virus—was used to produce immunity. Physicians in China had immunized patients from smallpox by removing scales from drying pustules of a person suffering from a mild case of smallpox, grinding the scales to a fine powder, and inserting the powder into the nose of the person to be protected.

Some vaccines are still produced from avirulent microbial strains that stimulate immunity to the related virulent strain. Other vaccines are made from killed virulent microbes, from isolated components of virulent microorganisms, or by genetic engineering techniques.

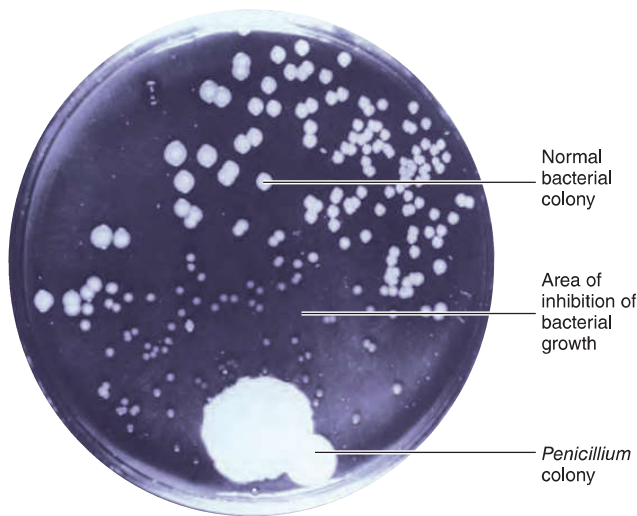
## CHECK YOUR UNDERSTANDING

- ✓ Summarize in your own words the germ theory of disease. **1-8**
- ✓ What is the importance of Koch's postulates? **1-9**
- ✓ What is the significance of Jenner's discovery? **1-10**

## The Birth of Modern Chemotherapy: Dreams of a "Magic Bullet"

After the relationship between microorganisms and disease was established, medical microbiologists next focused on the search for substances that could destroy pathogenic microorganisms without damaging the infected animal or human. Treatment of disease by using chemical substances is called **chemotherapy**. (The term also commonly refers to chemical treatment of non-infectious diseases, such as cancer.) Chemicals produced naturally by bacteria and fungi to act against other microorganisms are called **antibiotics**. Chemotherapeutic agents prepared from chemicals in the laboratory are called **synthetic drugs**. The success of chemotherapy is based on the fact that some chemicals are more poisonous to microorganisms than to the hosts infected by the microbes. Antimicrobial therapy will be discussed in further detail in Chapter 20.





**Figure 1.5 The discovery of penicillin.** Alexander Fleming took this photograph in 1928. The colony of *Penicillium* mold accidentally contaminated the plate and inhibited nearby bacterial growth.

**Q** Why do you think penicillin is no longer as effective as it once was?

### The First Synthetic Drugs

Paul Ehrlich, a German physician, was the imaginative thinker who fired the first shot in the chemotherapy revolution. As a medical student, Ehrlich speculated about a “magic bullet” that could hunt down and destroy a pathogen without harming the infected host. He then launched a search for such a bullet. In 1910, after testing hundreds of substances, he found a chemotherapeutic agent called *salvarsan*, an arsenic derivative effective against syphilis. The agent was named *salvarsan* because it was considered to offer salvation from syphilis and it contained arsenic. Before this discovery, the only known chemical in Europe’s medical arsenal was an extract from the bark of a South American tree, *quinine*, which had been used by Spanish conquistadors to treat malaria.

By the late 1930s, researchers had developed several other synthetic drugs that could destroy microorganisms. Most of these drugs were derivatives of dyes. This came about because the dyes synthesized and manufactured for fabrics were routinely tested for antimicrobial qualities by microbiologists looking for a “magic bullet.” In addition, *sulfonamides* (sulfa drugs) were synthesized at about the same time.

### A Fortunate Accident—Antibiotics

In contrast to the sulfa drugs, which were deliberately developed from a series of industrial chemicals, the first antibiotic was discovered by accident. Alexander Fleming, a Scottish physician and bacteriologist, almost tossed out some culture plates that had been contaminated by mold. Fortunately, he took a second look at the curious pattern of growth on the contaminated plates. Around the mold was a clear area where bacterial growth had been inhibited (Figure 1.5). Fleming was looking at a mold that

could inhibit the growth of a bacterium. The mold was later identified as *Penicillium notatum* (pen-i-sil’lē-um nō-tā’tum), later renamed *Penicillium chrysogenum* (krī-so’jen-um), and in 1928 Fleming named the mold’s active inhibitor *penicillin*. Thus, penicillin is an antibiotic produced by a fungus. The enormous usefulness of penicillin was not apparent until the 1940s, when it was finally tested clinically and mass produced.

Since these early discoveries, thousands of other antibiotics have been discovered. Unfortunately, antibiotics and other chemotherapeutic drugs are not without problems. Many antimicrobial chemicals are too toxic to humans for practical use; they kill the pathogenic microbes, but they also damage the infected host. For reasons we will discuss later, toxicity to humans is a particular problem in the development of drugs for treating viral diseases. Viral growth depends on life processes of normal host cells. Thus, there are very few successful antiviral drugs, because a drug that would interfere with viral reproduction would also likely affect uninfected cells of the body.

Another major problem associated with antimicrobial drugs is the emergence and spread of new strains of microorganisms that are resistant to antibiotics. Over the years, more and more microbes have developed resistance to antibiotics that at one time were very effective against them. Drug resistance results from genetic changes in microbes that enables them to tolerate a certain amount of an antibiotic that would normally inhibit them (see the box in Chapter 26, page 757). For example a microbe might produce chemicals (enzymes) that inactivate antibiotics, or a microbe might undergo changes to its surface that prevent an antibiotic from attaching to it or entering it.

The recent appearance of vancomycin-resistant *Staphylococcus aureus* and *Enterococcus faecalis* (en-te-rō-kok’kus fe-kā’lis) has alarmed health care professionals because it indicates that some previously treatable bacterial infections may soon be impossible to treat with antibiotics.

### CHECK YOUR UNDERSTANDING

What was Ehrlich’s “magic bullet”? 1-11

## Modern Developments in Microbiology

The quest to solve drug resistance, identify viruses, and develop vaccines requires sophisticated research techniques and correlated studies that were never dreamed of in the days of Koch and Pasteur.

The groundwork laid during the Golden Age of Microbiology provided the basis for several monumental achievements during the twentieth century (Table 1.2). New branches of microbiology were developed, including immunology and virology. Most recently, the development of a set of new methods called recombinant DNA technology has revolutionized research and practical applications in all areas of microbiology.

### Bacteriology, Mycology, and Parasitology

**Bacteriology**, the study of bacteria, began with van Leeuwenhoek’s first examination of tooth scrapings. New pathogenic

**TABLE 1.2** Selected Nobel Prizes Awarded for Research in Microbiology

Nobel Laureates	Year of Presentation	Country of Birth	Contribution
Ronald Ross	1902	England	Discovered how malaria is transmitted
Selman A. Waksman	1952	Ukraine	Discovered streptomycin
Hans A. Krebs	1953	Germany	Discovered chemical steps of the Krebs cycle in carbohydrate metabolism
John F. Enders, Thomas H. Weller, and Frederick C. Robbins	1954	United States	Cultured poliovirus in cell cultures
Joshua Lederberg, George Beadle, and Edward Tatum	1958	United States	Described genetic control of biochemical reactions
Frank Macfarlane Burnet and Peter Brian Medawar	1960	Australia Great Britain	Discovered acquired immune tolerance
César Milstein, Georges J. F. Köhler, and Niels Kai Jerne	1984	Argentina Germany Denmark	Developed a technique for producing monoclonal antibodies (single pure antibodies)
Susumu Tonegawa	1987	Japan	Described the genetics of antibody production
J. Michael Bishop and Harold E. Varmus	1989	United States	Discovered cancer-causing genes called oncogenes
Joseph E. Murray and E. Donnall Thomas	1990	United States	Performed the first successful organ transplants by using immunosuppressive agents
Edmond H. Fisher and Edwin G. Krebs	1992	United States	Discovered protein kinases, enzymes that regulate cell growth
Richard J. Roberts and Phillip A. Sharp	1993	Great Britain United States	Discovered that a gene can be separated onto different segments of DNA
Kary B. Mullis	1993	United States	Discovered the polymerase chain reaction to amplify (make multiple copies of) DNA
Peter C. Doherty and Rolf M. Zinkernagel	1996	Australia Switzerland	Discovered how cytotoxic T cells recognize virus-infected cells prior to destroying them
Peter Agre and Roderick MacKinnon	2003	United States	Discovered water and ion channels in plasma membranes
Aaron Ciechanover, Avram Hershko, and Irwin Rose	2004	Israel Israel United States	Discovered how cells dispose of unwanted proteins in proteasomes
Barry Marshall and J. Robin Warren	2005	Australia	Discovered that <i>Helicobacter pylori</i> causes peptic ulcers
Andrew Fire and Craig Mello	2006	United States	Discovered RNA interference (RNAi), or gene silencing, by double-stranded RNA
Harald zur Hausen	2008	Germany	Discovered that human papilloma viruses cause cervical cancer
Françoise Barré-Sinoussi and Luc Montagnier	2008	France	Discovered human immunodeficiency virus (HIV)
Venkatraman Ramakrishnan, Thomas A. Steitz, and Ada E. Yonath	2010	India United States Israel	Detailed study of the structure and function of ribosomes



(a) Rod of Asclepius, symbol of the medical profession.



(b) A parasitic guinea worm (*Dracunculus medinensis*) is removed from the subcutaneous tissue of a patient by winding it onto a stick. This procedure may have been used for the design of the symbol in part (a).

**Figure 1.6** Parasitology: the study of protozoa and parasitic worms.

**Q** How do you think parasitic worms survive and live off a human host?

bacteria are still discovered regularly. Many bacteriologists, like Pasteur, look at the roles of bacteria in food and the environment. One intriguing discovery came in 1997, when Heide Schulz discovered a bacterium large enough to be seen with the unaided eye (0.2 mm wide). This bacterium, named *Thiomargarita namibiensis* (thi'o-mă-găr-e-tă na'mīb-ē-ën-sis), lives in the mud on the African coast. *Thiomargarita* is unusual because of its size and its ecological niche. The bacterium consumes hydrogen sulfide, which would be toxic to mud-dwelling animals (Figure 11.28, page 327).

**Mycology**, the study of fungi, includes medical, agricultural, and ecological branches. Recall that Bassi's work leading up to the germ theory of disease focused on a fungal pathogen. Fungal infection rates have been rising during the past decade, accounting for 10% of hospital-acquired infections. Climatic and environmental changes (severe drought) are thought to account for the tenfold increase in *Coccidioides immitis* (kok-sid-ē-oi'dēz im'mi-tis) infections in California. New techniques for diagnosing and treating fungal infections are currently being investigated.

**Parasitology** is the study of protozoa and parasitic worms. Because many parasitic worms are large enough to be seen with the unaided eye, they have been known for thousands of years. It has been speculated that the medical symbol, the rod of Asclepius, represents the removal of parasitic guinea worms (Figure 1.6). Asclepius was a Greek physician who practiced about 1200 B.C. and was deified as the god of medicine.

The clearing of rain forests has exposed laborers to previously undiscovered parasites. Previously unknown parasitic diseases are also being found in patients whose immune systems have been suppressed by organ transplants, cancer chemotherapy, or AIDS.

Bacteriology, mycology, and parasitology are currently going through a "golden age" of classification. Recent advances in **genomics**, the study of all of an organism's genes, have allowed

scientists to classify bacteria and fungi according to their genetic relationships with other bacteria, fungi, and protozoa. These microorganisms were originally classified according to a limited number of visible characteristics.

## Immunology

**Immunology**, the study of immunity, dates back in Western culture to Jenner's first vaccine in 1796. Since then, knowledge about the immune system has accumulated steadily and expanded rapidly. Vaccines are now available for numerous diseases, including measles, rubella (German measles), mumps, chickenpox, pneumococcal pneumonia, tetanus, tuberculosis, influenza, whooping cough, polio, and hepatitis B. The smallpox vaccine was so effective that the disease has been eliminated. Public health officials estimate that polio will be eradicated within a few years because of the polio vaccine.

A major advance in immunology occurred in 1933, when Rebecca Lancefield proposed that streptococci be classified according to serotypes (variants within a species) based on certain components in the cell walls of the bacteria. Streptococci are responsible for a variety of diseases, such as sore throat (strep throat), streptococcal toxic shock, and septicemia (blood poisoning). Her research permits the rapid identification of specific pathogenic streptococci based on immunological techniques.

In 1960, interferons, substances generated by the body's own immune system, were discovered. Interferons inhibit replication of viruses and have triggered considerable research related to the treatment of viral diseases and cancer. One of today's biggest challenges for immunologists is learning how the immune system might be stimulated to ward off the virus responsible for AIDS, a disease that destroys the immune system.

## Virology

The study of viruses, **virology**, originated during the Golden Age of Microbiology. In 1892, Dmitri Iwanowski reported that the organism that caused mosaic disease of tobacco was so small that it passed through filters fine enough to stop all known bacteria. At the time, Iwanowski was not aware that the organism in question was a virus. In 1935, Wendell Stanley demonstrated that the organism, called tobacco mosaic virus (TMV), was fundamentally different from other microbes and so simple and homogeneous that it could be crystallized like a chemical compound. Stanley's work facilitated the study of viral structure and chemistry. Since the development of the electron microscope in the 1940s, microbiologists have been able to observe the structure of viruses in detail, and today much is known about their structure and activity.

## Recombinant DNA Technology

Microorganisms can now be genetically modified to manufacture large amounts of human hormones and other urgently needed medical substances. In the late 1960s, Paul Berg showed that fragments of human or animal DNA (genes) that code for important proteins can be attached to bacterial DNA. The resulting hybrid was the



first example of **recombinant DNA**. When recombinant DNA is inserted into bacteria (or other microbes), it can be used to make large quantities of the desired protein. The technology that developed from this technique is called **recombinant DNA technology**. Its origins can be found in two related fields. The first, **microbial genetics**, studies the mechanisms by which microorganisms inherit traits. The second, **molecular biology**, specifically studies how genetic information is carried in molecules of DNA and how DNA directs the synthesis of proteins.

Although molecular biology encompasses all organisms, much of our knowledge of how genes determine specific traits has been revealed through experiments with bacteria. Through the 1930s, all genetic research was based on the study of plant and animal cells. But in the 1940s, scientists turned to unicellular organisms, primarily bacteria, which have several advantages for genetic and biochemical research. For one thing, bacteria are less complex than plants and animals. For another, the life cycles of many bacteria last less than an hour, so scientists can cultivate very large numbers of bacteria for study in a relatively short time.

Once science turned to the study of unicellular life, rapid progress was made in genetics. In 1941, George W. Beadle and Edward L. Tatum demonstrated the relationship between genes and enzymes. DNA was established as the hereditary material in 1944 by Oswald Avery, Colin MacLeod, and Maclyn McCarty. In 1946, Joshua Lederberg and Edward L. Tatum discovered that genetic material could be transferred from one bacterium to another by a process called conjugation. Then, in 1953, James Watson and Francis Crick proposed a model for the structure and replication of DNA. The early 1960s witnessed a further explosion of discoveries relating to the way DNA controls protein synthesis. In 1961, François Jacob and Jacques Monod discovered messenger RNA (ribonucleic acid), a chemical involved in protein synthesis, and later they made the first major discoveries about the regulation of gene function in bacteria. During the same period, scientists were able to break the genetic code and thus understand how the information for protein synthesis in messenger RNA is translated into the amino acid sequence for making proteins.

### CHECK YOUR UNDERSTANDING

- ✓ Define *bacteriology, mycology, parasitology, immunology, and virology*. **1-12**
- ✓ Differentiate microbial genetics from molecular biology. **1-13**

## Microbes and Human Welfare

### LEARNING OBJECTIVES

- 1-14** List at least four beneficial activities of microorganisms.
- 1-15** Name two examples of biotechnology that use recombinant DNA technology and two examples that do not.

As mentioned earlier, only a minority of all microorganisms are pathogenic. Microbes that cause food spoilage, such as soft spots on fruits and vegetables, decomposition of meats, and rancidity

of fats and oils, are also a minority. The vast majority of microbes benefit humans, other animals, and plants in many ways. For example, microbes produce methane and ethanol that can be used as alternative fuels to generate electricity and power vehicles. Biotechnology companies are using bacterial enzymes to break down plant cellulose so that yeast can metabolize the resulting simple sugars and produce ethanol. The following sections outline some of these beneficial activities. In later chapters, we will discuss these activities in greater detail.

## Recycling Vital Elements

Discoveries made by two microbiologists in the 1880s have formed the basis for today's understanding of the biogeochemical cycles that support life on Earth. Martinus Beijerinck and Sergei Winogradsky were the first to show how bacteria help recycle vital elements between the soil and the atmosphere. **Microbial ecology**, the study of the relationship between microorganisms and their environment, originated with the work of these scientists. Today, microbial ecology has branched out and includes the study of how microbial populations interact with plants and animals in various environments. Among the concerns of microbial ecologists are water pollution and toxic chemicals in the environment.

The chemical elements carbon, nitrogen, oxygen, sulfur, and phosphorus are essential for life and abundant, but not necessarily in forms that organisms can use. Microorganisms are primarily responsible for converting these elements into forms that plants and animals can use. Microorganisms, primarily bacteria and fungi, return carbon dioxide to the atmosphere when they decompose organic wastes and dead plants and animals. Algae, cyanobacteria, and higher plants use the carbon dioxide during photosynthesis to produce carbohydrates for animals, fungi, and bacteria. Nitrogen is abundant in the atmosphere but in that form is not usable by plants and animals. Only bacteria can naturally convert atmospheric nitrogen to a form available to plants and animals.

## Sewage Treatment: Using Microbes to Recycle Water

Our society's growing awareness of the need to preserve the environment has made people more conscious of the responsibility to recycle precious water and prevent the pollution of rivers and oceans. One major pollutant is sewage, which consists of human excrement, waste water, industrial wastes, and surface runoff. Sewage is about 99.9% water, with a few hundredths of 1% suspended solids. The remainder is a variety of dissolved materials.

Sewage treatment plants remove the undesirable materials and harmful microorganisms. Treatments combine various physical processes with the action of beneficial microbes. Large solids such as paper, wood, glass, gravel, and plastic are removed from sewage; left behind are liquid and organic materials that bacteria convert into such by-products as carbon dioxide, nitrates, phosphates, sulfates, ammonia, hydrogen sulfide, and methane. (We will discuss sewage treatment in detail in Chapter 27.)

## Bioremediation: Using Microbes to Clean Up Pollutants

In 1988, scientists began using microbes to clean up pollutants and toxic wastes produced by various industrial processes. For example, some bacteria can actually use pollutants as energy sources; others produce enzymes that break down toxins into less harmful substances. By using bacteria in these ways—a process known as **bioremediation**—toxins can be removed from underground wells, chemical spills, toxic waste sites, and oil spills, such as the massive oil spill from an offshore drilling rig in the Gulf of Mexico on April 20, 2010 (see also the box in Chapter 2, page 32). In addition, bacterial enzymes are used in drain cleaners to remove clogs without adding harmful chemicals to the environment. In some cases, microorganisms indigenous to the environment are used; in others, genetically modified microbes are used. Among the most commonly used microbes are certain species of bacteria of the genera *Pseudomonas* (sū-dō-mō'nas) and *Bacillus* (bä-sil'lus). *Bacillus* enzymes are also used in household detergents to remove spots from clothing.

## Insect Pest Control by Microorganisms

Besides spreading diseases, insects can cause devastating crop damage. Insect pest control is therefore important for both agriculture and the prevention of human disease.

The bacterium *Bacillus thuringiensis* (thür-in-jē-en'sis) has been used extensively in the United States to control such pests as alfalfa caterpillars, bollworms, corn borers, cabbageworms, tobacco budworms, and fruit tree leaf rollers. It is incorporated into a dusting powder that is applied to the crops these insects eat. The bacteria produce protein crystals that are toxic to the digestive systems of the insects. The toxin gene also has been inserted into some plants to make them insect resistant.

By using microbial rather than chemical insect control, farmers can avoid harming the environment. Many chemical insecticides, such as DDT, remain in the soil as toxic pollutants and are eventually incorporated into the food chain.

## Modern Biotechnology and Recombinant DNA Technology

Earlier, we touched on the commercial use of microorganisms to produce some common foods and chemicals. Such practical applications of microbiology are called **biotechnology**. Although biotechnology has been used in some form for centuries, techniques have become much more sophisticated in the past few decades. In the last several years, biotechnology has undergone a revolution through the advent of recombinant DNA technology to expand the potential of bacteria, viruses, and yeast cells and other fungi as miniature biochemical factories. Cultured plant and animal cells, as well as intact plants and animals, are also used as recombinant cells and organisms.

The applications of recombinant DNA technology are increasing with each passing year. Recombinant DNA techniques have been used thus far to produce a number of natural proteins, vaccines, and enzymes. Such substances have great potential for medical use; some of them are described in Table 9.1 on page 248.

A very exciting and important outcome of recombinant DNA techniques is **gene therapy**—inserting a missing gene or replacing a defective one in human cells. This technique uses a harmless virus to carry the missing or new gene into certain host cells, where the gene is picked up and inserted into the appropriate chromosome. Since 1990, gene therapy has been used to treat patients with adenosine deaminase (ADA) deficiency, a cause of severe combined immunodeficiency disease (SCID), in which cells of the immune system are inactive or missing; Duchenne's muscular dystrophy, a muscle-destroying disease; cystic fibrosis, a disease of the secreting portions of the respiratory passages, pancreas, salivary glands, and sweat glands; and LDL-receptor deficiency, a condition in which low-density lipoprotein (LDL) receptors are defective and LDL cannot enter cells. The LDL remains in the blood in high concentrations and increases the risk of atherosclerosis and coronary artery disease because it leads to fatty plaque formation in blood vessels. Results are still being evaluated. Other genetic diseases may also be treatable by gene therapy in the future, including hemophilia, an inability of the blood to clot normally; diabetes, elevated blood sugar levels; sickle cell disease, an abnormal kind of hemoglobin; and one type of hypercholesterolemia, high blood cholesterol.

Beyond medical applications, recombinant DNA techniques have also been applied to agriculture. For example, genetically altered strains of bacteria have been developed to protect fruit against frost damage, and bacteria are being modified to control insects that damage crops. Recombinant DNA has also been used to improve the appearance, flavor, and shelf life of fruits and vegetables. Potential agricultural uses of recombinant DNA include drought resistance, resistance to insects and microbial diseases, and increased temperature tolerance in crops.

### CHECK YOUR UNDERSTANDING

- ✓ Name two beneficial uses of bacteria. **1-14**
- ✓ Differentiate biotechnology from recombinant DNA technology. **1-15**

## Microbes and Human Disease

### LEARNING OBJECTIVES

- 1-16** Define *normal microbiota* and *resistance*.
- 1-17** Define *biofilm*.
- 1-18** Define *emerging infectious disease*.

## Normal Microbiota

We all live from birth until death in a world filled with microbes, and we all have a variety of microorganisms on and inside our

bodies. These microorganisms make up our **normal microbiota**, or *flora*\* (Figure 1.7). The normal microbiota not only do us no harm, but also in some cases can actually benefit us. For example, some normal microbiota protect us against disease by preventing the overgrowth of harmful microbes, and others produce useful substances such as vitamin K and some B vitamins. Unfortunately, under some circumstances normal microbiota can make us sick or infect people we contact. For instance, when some normal microbiota leave their habitat, they can cause disease.

When is a microbe a welcome part of a healthy human, and when is it a harbinger of disease? The distinction between health and disease is in large part a balance between the natural defenses of the body and the disease-producing properties of microorganisms. Whether our bodies overcome the offensive tactics of a particular microbe depends on our **resistance**—the ability to ward off diseases. Important resistance is provided by the barrier of the skin, mucous membranes, cilia, stomach acid, and antimicrobial chemicals such as interferons. Microbes can be destroyed by white blood cells, by the inflammatory response, by fever, and by specific responses of our immune system. Sometimes, when our natural defenses are not strong enough to overcome an invader, they have to be supplemented by antibiotics or other drugs.

### Clinical Case

Staph is the common name for *Staphylococcus aureus* bacteria, which are carried on the skin of about 30% of the human population. Although Andrea is diligent about taking her antibiotic as prescribed, she doesn't seem to be improving. After 3 days, the lesion on her wrist is even larger than before and is now draining yellow pus. Andrea also develops a fever. Her mother insists that she call her doctor to tell him about the latest developments.

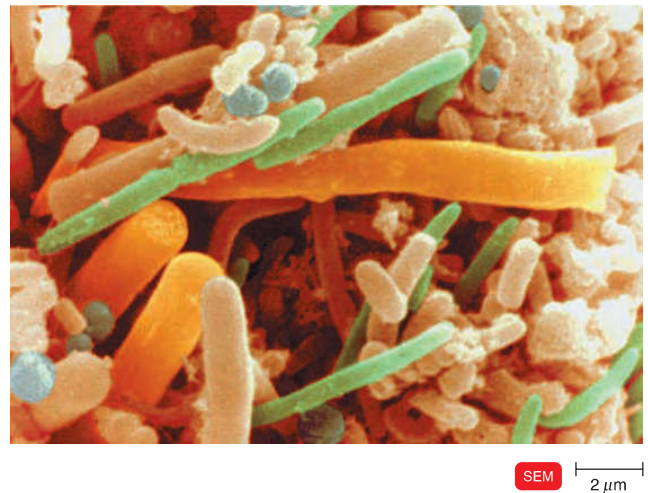
**Why does Andrea's infection persist after treatment?**

2 17 19 20 21

### Biofilms

In nature, microorganisms may exist as single cells that float or swim independently in a liquid, or they may attach to each other and/or some usually solid surface. This latter mode of behavior is called a **biofilm**, a complex aggregation of microbes. The slime covering a rock in a lake is a biofilm. Use your tongue to feel the biofilm on your teeth. Biofilms can be beneficial. They protect your mucous membranes from harmful microbes, and biofilms in lakes are an important food for aquatic animals. Biofilms can also be harmful. They can clog water pipes, and on medical implants

\* At one time, bacteria and fungi were thought to be plants, and thus the term *flora* was used.



**Figure 1.7** Several types of bacteria found as part of the normal microbiota on the surface of the human tongue.

**Q** How do we benefit from the production of vitamin K by microbes?

such as joint prostheses and catheters (Figure 1.8), they can cause such infections as endocarditis (inflammation of the heart). Bacteria in biofilms are often resistant to antibiotics because the biofilm offers a protective barrier. See the box in Chapter 3 on page 56. Biofilms will be discussed in Chapter 6.

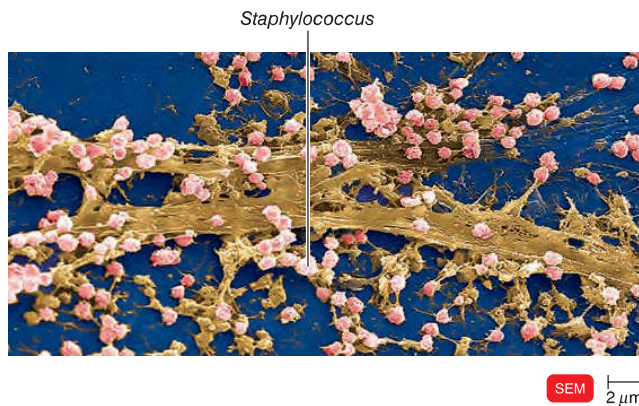
### Infectious Diseases

An **infectious disease** is a disease in which pathogens invade a susceptible host, such as a human or an animal. In the process, the pathogen carries out at least part of its life cycle inside the host, and disease frequently results. By the end of World War II, many people believed that infectious diseases were under control. They thought malaria would be eradicated through the use of the insecticide DDT to kill mosquitoes, that a vaccine would prevent diphtheria, and that improved sanitation measures would help prevent cholera transmission. Malaria is far from eliminated. Since 1986, local outbreaks have been identified in New Jersey, California, Florida, New York, and Texas, and the disease infects 300 million people worldwide. In 1994, diphtheria appeared in the United States, brought by travelers from the newly independent states of the former Soviet Union, which were experiencing a massive diphtheria epidemic. The epidemic was brought under control in 1998. Cholera outbreaks still occur in less-developed parts of the world.

### Emerging Infectious Diseases

These recent outbreaks point to the fact that infectious diseases are not disappearing, but rather seem to be reemerging and increasing. In addition, a number of new diseases—**emerging infectious diseases (EIDs)**—have cropped up in recent years. These are diseases that are new or changing and are increasing





**Figure 1.8 Biofilm on a catheter.** *Staphylococcus* bacteria stick to solid surfaces, forming a slimy layer. Bacteria that break away from this biofilm can cause infections.

**Q** How does a biofilm's protective barrier make it resistant to antibiotics?

or have the potential to increase in incidence in the near future. Some of the factors that have contributed to the development of EIDs are evolutionary changes in existing organisms (e.g., *Vibrio cholerae*; vib'rē-ō kol'-er-ī); the spread of known diseases to new geographic regions or populations by modern transportation (e.g., West Nile virus); and increased human exposure to new, unusual infectious agents in areas that are undergoing ecologic changes such as deforestation and construction (e.g., Venezuelan hemorrhagic virus). EIDs also develop as a result of antimicrobial resistance (e.g., vancomycin-resistant *S. aureus*). An increasing number of incidents in recent years highlights the extent of the problem.

**H1N1 influenza (flu)**, also known as *swine flu*, is a type of influenza caused by a new virus called *influenza H1N1*. H1N1 was first detected in the United States in April 2009. In June 2009, the World Health Organization declared H1N1 flu to be a *global pandemic disease* (a disease that affects large numbers of individuals in a short period of time and occurs worldwide).

**Avian influenza A (H5N1), or bird flu**, caught the attention of the public in 2003, when it killed millions of poultry and 24 people in eight countries in southeast Asia. Avian influenza viruses occur in birds worldwide. Certain wild birds, particularly waterfowl, do not get sick but carry the virus in their intestines and shed it in saliva, nasal secretions, and feces. Most often, the wild birds spread influenza to domesticated birds, in which the virus causes death.

Influenza A viruses are found in many different animals, including ducks, chickens, pigs, whales, horses, and seals. Normally, each subtype of influenza A virus is specific to certain species. However, influenza A viruses normally seen in one species sometimes can cross over and cause illness in another species, and all subtypes of influenza A virus can infect pigs. Although

it is unusual for people to get influenza infections directly from animals, sporadic human infections and outbreaks caused by certain avian influenza A viruses and pig influenza viruses have been reported. As of 2008, avian influenza had sickened 242 people, and about half of them died. Fortunately, the virus has not yet evolved to be transmitted successfully among humans.

Human infections with avian influenza viruses detected since 1997 have not resulted in sustained human-to-human transmission. However, because influenza viruses have the potential to change and gain the ability to spread easily between people, monitoring for human infection and person-to-person transmission is important (see the box in Chapter 13 on page 374). The U.S. Food and Drug Administration (FDA) approved a human vaccine against the avian influenza virus in April 2007.

Antibiotics are critical in treating bacterial infections. However, years of overuse and misuse of these drugs have created environments in which antibiotic-resistant bacteria thrive. Random mutations in bacterial genes can make a bacterium resistant to an antibiotic. In the presence of that antibiotic, this bacterium has an advantage over other, susceptible bacteria and is able to proliferate. Antibiotic-resistant bacteria have become a global health crisis.

*Staphylococcus aureus* causes a wide range of human infections from pimples and boils to pneumonia, food poisoning, and surgical wound infections, and it is a significant cause of hospital-associated infections. After penicillin's initial success in treating *S. aureus* infection, penicillin-resistant *S. aureus* became a major threat in hospitals in the 1950s, requiring the use of methicillin. In the 1980s, **methicillin-resistant *S. aureus***, called **MRSA**, emerged and became endemic in many hospitals, leading to increasing use of vancomycin. In the late 1990s, *S. aureus* infections that were less sensitive to vancomycin (**vancomycin-intermediate *S. aureus***, or **VISA**) were reported. In 2002, an infection caused by **vancomycin-resistant *S. aureus*** (**VRSA**) in a patient in the United States was reported.

In March 2010, the World Health Organization (WHO) reported that in some parts of the world (such as northwestern Russia) about 28% of all individuals with tuberculosis (TB) had the multidrug-resistant form of the disease (MDR-TB). Multidrug-resistant TB is caused by bacteria that are resistant to at least the antibiotics isoniazid and rifampicin, the most effective drugs against tuberculosis.

The antibacterial substances added to various household cleaning products are similar to antibiotics in many ways. When used correctly, they inhibit bacterial growth. However, wiping every household surface with these antibacterial agents creates an environment in which the resistant bacteria survive. Unfortunately, when you really need to disinfect your homes and hands—for example, when a family member comes home from a hospital and is still vulnerable to infection—you may encounter mainly resistant bacteria.

Routine housecleaning and handwashing are necessary, but standard soaps and detergents (without added antibacterials) are fine for these tasks. In addition, quickly evaporating chemicals, such as chlorine bleach, alcohol, ammonia, and hydrogen peroxide, remove potentially pathogenic bacteria but do not leave residues that encourage the growth of resistant bacteria.

### Clinical Case

The *S. aureus* bacterium responsible for Andrea's infection is resistant to the  $\beta$ -lactam antibiotic prescribed by Andrea's doctor. Concerned about what his patient is telling him, Andrea's doctor calls the local hospital to let them know he is sending a patient over. In the emergency department, a nurse swabs Andrea's wound and sends it to the hospital lab for culturing. The culture shows that Andrea's infection is caused by methicillin-resistant *Staphylococcus aureus* (MRSA). MRSA produces  $\beta$ -lactamase, an enzyme that destroys  $\beta$ -lactam antibiotics. The attending physician surgically drains the pus from the sore on Andrea's wrist.

#### How does antibiotic resistance develop?

2 17 19 20 21

**West Nile encephalitis (WNE)** is inflammation of the brain caused by West Nile virus (see Chapter 8). WNE was first diagnosed in the West Nile region of Uganda in 1937. In 1999 the virus made its first North American appearance in humans in New York City. In 2007, West Nile virus infected over 3600 people in 43 states. West Nile virus is now established in non-migratory birds in 48 states. The virus, which is carried by birds, is transmitted between birds—and to horses and humans—by mosquitoes. West Nile virus may have arrived in the United States in an infected traveler or in migratory birds.

In 1996, countries worldwide were refusing to import beef from the United Kingdom, where hundreds of thousands of cattle born after 1988 had to be killed because of an epidemic of **bovine spongiform encephalopathy** (en-sef-a-lop'a-thē), also called **BSE** or **mad cow disease**. BSE first came to the attention of microbiologists in 1986 as one of a handful of diseases caused by an infectious protein called a *prion*. Studies suggest that the source of disease was cattle feed prepared from sheep infected with their own version of the disease. Cattle are herbivores (plant eaters), but adding protein to their feed improves their growth and health. **Creutzfeldt-Jakob disease** (kroits'felt yä'kôb), or **CJD**, is a human disease also caused by a prion. The incidence of CJD in the United Kingdom is similar to the incidence in other countries. However, by 2005 the United Kingdom reported 154 human cases of CJD caused by a new variant related to the bovine disease (see Chapter 22).

*Escherichia coli* is a normal inhabitant of the large intestine of vertebrates, including humans, and its presence is beneficial

because it helps produce certain vitamins and breaks down otherwise undigestible foodstuffs (see Chapter 25). However, a strain called *E. coli* O157:H7 causes bloody diarrhea when it grows in the intestines. This strain was first recognized in 1982 and since then has emerged as a public health problem. It is now one of the leading causes of diarrhea worldwide. In 1996, some 9000 people in Japan became ill, and 7 died, as a result of infection by *E. coli* O157:H7. The recent outbreaks of *E. coli* O157:H7 in the United States, associated with contamination of undercooked meat and unpasteurized beverages, have led public health officials to call for the development of new methods of testing for bacteria in food.

In 1995, infections of so-called **flesh-eating bacteria** were reported on the front pages of major newspapers. The bacteria are more correctly named invasive group A *Streptococcus* (strep-tō-kok'kus), or IGAS. Rates of IGAS in the United States, Scandinavia, England, and Wales have been increasing.

In 1995, a hospital laboratory technician in Democratic Republic of Congo (DROC) who had fever and bloody diarrhea underwent surgery for a suspected perforated bowel. Afterward he started hemorrhaging, and his blood began clotting in his blood vessels. A few days later, health care workers in the hospital where he was staying developed similar symptoms. One of them was transferred to a hospital in a different city; personnel in the second hospital who cared for this patient also developed symptoms. By the time the epidemic was over, 315 people had contracted **Ebola hemorrhagic fever** (hem-ô-raj'ik), or **EHF**, and over 75% of them died. The epidemic was controlled when microbiologists instituted training on the use of protective equipment and educational measures in the community. Close personal contact with infectious blood or other body fluids or tissue (see Chapter 23) leads to human-to-human transmission.

Microbiologists first isolated Ebola viruses from humans during earlier outbreaks in DROC in 1976. (The virus is named after Congo's Ebola River.) In 2008, an Ebola virus outbreak occurred in Uganda with 149 cases. In 1989 and 1996, outbreaks among monkeys imported into the United States from the Philippines were caused by another Ebola virus but were not associated with human disease.

Recorded cases of **Marburg virus**, another hemorrhagic fever virus, are rare. The first cases were laboratory workers in Europe who handled African green monkeys from Uganda. Four outbreaks were identified in Africa between 1975 and 1998, involving 2 to 154 people with 56% mortality. In 2004, an outbreak killed 227 people. Microbiologists have been studying many animals but have not yet discovered the natural reservoir (source) of EHF and Marburg viruses.

In 1993, an outbreak of **cryptosporidiosis** (krip-tō-spō-rid-ē-ō'sis) transmitted through the public water supply in Milwaukee, Wisconsin, resulted in diarrheal illness in an estimated 403,000 persons. The microorganism responsible for this outbreak was the protozoan *Cryptosporidium* (krip-tō-spō-ri'dē-um). First

reported as a cause of human disease in 1976, it is responsible for up to 30% of the diarrheal illness in developing countries. In the United States, transmission has occurred via drinking water, swimming pools, and contaminated hospital supplies.

**AIDS (acquired immunodeficiency syndrome)** first came to public attention in 1981 with reports from Los Angeles that a few young homosexual men had died of a previously rare type of pneumonia known as *Pneumocystis* (nü-mō-sis'tis) pneumonia. These men had experienced a severe weakening of the immune system, which normally fights infectious diseases. Soon these cases were correlated with an unusual number of occurrences of a rare form of cancer, Kaposi's sarcoma, among young homosexual men. Similar increases in such rare diseases were found among hemophiliacs and intravenous drug users.

Researchers quickly discovered that the cause of AIDS was a previously unknown virus (see Figure 1.1e). The virus, now called **human immunodeficiency virus (HIV)**, destroys CD4<sup>+</sup> T cells, one type of white blood cell important to immune system defenses. Sickness and death result from microorganisms or cancerous cells that might otherwise have been defeated by the body's natural defenses. So far, the disease has been inevitably fatal once symptoms develop.

By studying disease patterns, medical researchers found that HIV could be spread through sexual intercourse, by contaminated needles, from infected mothers to their newborns via breast milk, and by blood transfusions—in short, by the transmission of body fluids from one person to another. Since

1985, blood used for transfusions has been carefully checked for the presence of HIV, and it is now quite unlikely that the virus can be spread by this means.

By the end of 2010, over 1 million people in the United States are living with AIDS. Over 50,000 Americans become infected and 18,000 die each year. As of 2010, health officials estimated that 1.3 million Americans have HIV infection. In 2009, the World Health Organization (WHO) estimated that over 33 million people worldwide are living with HIV/AIDS and that 7500 new infections occur every day.

Since 1994, new treatments have extended the life span of people with AIDS; however, approximately 40,000 new cases occur annually in the United States. The majority of individuals with AIDS are in the sexually active age group. Because heterosexual partners of AIDS sufferers are at high risk of infection, public health officials are concerned that even more women and minorities will contract AIDS. In 1997, HIV diagnoses began increasing among women and minorities. Among the AIDS cases reported in 2009, 26% were women, and 49% were African American.

In the months and years to come, scientists will continue to apply microbiological techniques to help them learn more about the structure of the deadly HIV, how it is transmitted, how it grows in cells and causes disease, how drugs can be directed against it, and whether an effective vaccine can be developed. Public health officials have also focused on prevention through education.

AIDS poses one of this century's most formidable health threats, but it is not the first serious epidemic of a sexually transmitted disease. Syphilis was also once a fatal epidemic disease. As recently as 1941, syphilis caused an estimated 14,000 deaths per year in the United States. With few drugs available for treatment and no vaccines to prevent it, efforts to control the disease focused mainly on altering sexual behavior and on the use of condoms. The eventual development of drugs to treat syphilis contributed significantly to preventing the spread of the disease. According to the Centers for Disease Control and Prevention (CDC), reported cases of syphilis dropped from a record high of 575,000 in 1943 to an all-time low of 5979 cases in 2004. Since then, however, the number of cases has been increasing.

Just as microbiological techniques helped researchers in the fight against syphilis and smallpox, they will help scientists discover the causes of new emerging infectious diseases in the twenty-first century. Undoubtedly there will be new diseases. Ebola virus and *Influenzavirus* are examples of viruses that may be changing their abilities to infect different host species. Emerging infectious diseases will be discussed further in Chapter 14 on page 417.

Infectious diseases may reemerge because of antibiotic resistance (see the box in Chapter 26 on page 757) and through the use of microorganisms as weapons. (See the box in Chapter 23 on page 651.) The breakdown of public health measures for previously controlled infections has resulted in unexpected cases of tuberculosis, whooping cough, and diphtheria (see Chapter 24).

### Clinical Case

Mutations develop randomly in bacteria: some mutations are lethal, some have no effect, and some may be beneficial. Once these mutations develop, the offspring of the mutated parent cells also carry the same mutation. Because they have an advantage in the presence of the antibiotic, bacteria that are resistant to antibiotics soon outnumber those that are susceptible to antibiotic therapy. The widespread use of antibiotics selectively allows the resistant bacteria to grow, whereas the susceptible bacteria are killed. Eventually, almost the entire population of bacteria is resistant to the antibiotic.

The emergency department physician prescribes a different antibiotic, vancomycin, which will kill the MRSA in Andrea's wrist. She also explains to Andrea what MRSA is and why it's important they find out where Andrea acquired the potentially lethal bacteria.

**What can the emergency department physician tell Andrea about MRSA?**

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**CHECK YOUR UNDERSTANDING**

- ✓ Differentiate normal microbiota and infectious disease. **1-16**
- ✓ Why are biofilms important? **1-17**
- ✓ What factors contribute to the emergence of an infectious disease? **1-18**

\* \* \*

The diseases we have mentioned are caused by viruses, bacteria, protozoa, and prions—types of microorganisms. This book introduces you to the enormous variety of microscopic organisms. It shows you how microbiologists use specific techniques and procedures to study the microbes that cause such diseases as AIDS and diarrhea—and diseases that have yet to be discovered. You will also learn how the body responds to microbial infection and how certain drugs combat microbial diseases. Finally, you will learn about the many beneficial roles that microbes play in the world around us.

**Clinical Case Resolved**

The first MRSA was health care–associated MRSA (HA-MRSA), transmitted between staff and patients in health care settings. In the 1990s, infections by a genetically different strain, community-associated MRSA

(CA-MRSA), emerged as a major cause of skin disease in the United States. CA-MRSA enters skin abrasions from environmental surfaces or other people. Andrea has never been hospitalized before now, so they are able to rule out the hospital as the source of infection. Her college courses are all online, so she didn't contract MRSA at the university, either. The local health department sends someone to her family home to swab for the bacteria there.

MRSA is isolated from Andrea's living room sofa, but how did it get there? After speaking with the family, the representative from the health department, knowing that clusters of CA-MRSA infections have been seen among athletes suggests swabbing the mats used by the gymnasts at the school Andrea's sister attends. The cultures come back positive for MRSA. Andrea's sister, although not infected, transferred the bacteria from her skin to the sofa, where Andrea laid her arm. (A person can carry MRSA on the skin without becoming infected.) The bacteria entered through a scratch on Andrea's wrist.

2 17 19 20 **21****Study Outline****MasteringMICROBIOLOGY™**

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**Microbes in Our Lives** (p. 2)

1. Living things too small to be seen with the unaided eye are called microorganisms.
2. Microorganisms are important in maintaining Earth's ecological balance.
3. Some microorganisms live in humans and other animals and are needed to maintain good health.
4. Some microorganisms are used to produce foods and chemicals.
5. Some microorganisms cause disease.

**Naming and Classifying Microorganisms** (pp. 2–6)**Nomenclature** (p. 3)

1. In a nomenclature system designed by Carolus Linnaeus (1735), each living organism is assigned two names.
2. The two names consist of a genus and a specific epithet, both of which are underlined or italicized.

**Types of Microorganisms** (pp. 3–6)

3. Bacteria are unicellular organisms. Because they have no nucleus, the cells are described as prokaryotic.

4. The three major basic shapes of bacteria are bacillus, coccus, and spiral.
5. Most bacteria have a peptidoglycan cell wall; they divide by binary fission, and they may possess flagella.
6. Bacteria can use a wide range of chemical substances for their nutrition.
7. Archaea consist of prokaryotic cells; they lack peptidoglycan in their cell walls.
8. Archaea include methanogens, extreme halophiles, and extreme thermophiles.
9. Fungi (mushrooms, molds, and yeasts) have eukaryotic cells (cells with a true nucleus). Most fungi are multicellular.
10. Fungi obtain nutrients by absorbing organic material from their environment.
11. Protozoa are unicellular eukaryotes.
12. Protozoa obtain nourishment by absorption or ingestion through specialized structures.
13. Algae are unicellular or multicellular eukaryotes that obtain nourishment by photosynthesis.
14. Algae produce oxygen and carbohydrates that are used by other organisms.
15. Viruses are noncellular entities that are parasites of cells.
16. Viruses consist of a nucleic acid core (DNA or RNA) surrounded by a protein coat. An envelope may surround the coat.
17. The principal groups of multicellular animal parasites are flatworms and roundworms, collectively called helminths.
18. The microscopic stages in the life cycle of helminths are identified by traditional microbiological procedures.

**Classification of Microorganisms** (p. 6)

19. All organisms are classified into Bacteria, Archaea, and Eukarya. Eukarya include protists, fungi, plants, and animals.

**A Brief History of Microbiology** (pp. 6–15)**The First Observations** (p. 6)

1. Robert Hooke observed that cork was composed of “little boxes”; he introduced the term *cell* (1665).
2. Hooke’s observations laid the groundwork for development of the cell theory, the concept that all living things are composed of cells.
3. Anton van Leeuwenhoek, using a simple microscope, was the first to observe microorganisms (1673).

**The Debate over Spontaneous Generation** (pp. 6–8)

4. Until the mid-1880s, many people believed in spontaneous generation, the idea that living organisms could arise from nonliving matter.
5. Francesco Redi demonstrated that maggots appear on decaying meat only when flies are able to lay eggs on the meat (1668).
6. John Needham claimed that microorganisms could arise spontaneously from heated nutrient broth (1745).
7. Lazzaro Spallanzani repeated Needham’s experiments and suggested that Needham’s results were due to microorganisms in the air entering his broth (1765).
8. Rudolf Virchow introduced the concept of biogenesis: living cells can arise only from preexisting cells (1858).
9. Louis Pasteur demonstrated that microorganisms are in the air everywhere and offered proof of biogenesis (1861).
10. Pasteur’s discoveries led to the development of aseptic techniques used in laboratory and medical procedures to prevent contamination by microorganisms.

**The Golden Age of Microbiology** (pp. 8–11)

11. The science of microbiology advanced rapidly between 1857 and 1914.
12. Pasteur found that yeasts ferment sugars to alcohol and that bacteria can oxidize the alcohol to acetic acid.
13. A heating process called pasteurization is used to kill bacteria in some alcoholic beverages and milk.
14. Agostino Bassi (1835) and Pasteur (1865) showed a causal relationship between microorganisms and disease.
15. Joseph Lister introduced the use of a disinfectant to clean surgical wounds in order to control infections in humans (1860s).
16. Robert Koch proved that microorganisms cause disease. He used a sequence of procedures, now called Koch’s postulates (1876), that are used today to prove that a particular microorganism causes a particular disease.
17. In a vaccination, immunity (resistance to a particular disease) is conferred by inoculation with a vaccine.
18. In 1798, Edward Jenner demonstrated that inoculation with cowpox material provides humans with immunity to smallpox.
19. About 1880, Pasteur discovered that avirulent bacteria could be used as a vaccine for fowl cholera; he coined the word *vaccine*.
20. Modern vaccines are prepared from living avirulent microorganisms or killed pathogens, from isolated components of pathogens, and by recombinant DNA techniques.

**The Birth of Modern Chemotherapy:****Dreams of a “Magic Bullet”** (pp. 11–12)

21. Chemotherapy is the chemical treatment of a disease.

22. Two types of chemotherapeutic agents are synthetic drugs (chemically prepared in the laboratory) and antibiotics (substances produced naturally by bacteria and fungi to inhibit the growth of other microorganisms).
23. Paul Ehrlich introduced an arsenic-containing chemical called salvarsan to treat syphilis (1910).
24. Alexander Fleming observed that the *Penicillium* fungus inhibited the growth of a bacterial culture. He named the active ingredient penicillin (1928).
25. Penicillin has been used clinically as an antibiotic since the 1940s.
26. Researchers are tackling the problem of drug-resistant microbes.

**Modern Developments in Microbiology** (pp. 12–15)

27. Bacteriology is the study of bacteria, mycology is the study of fungi, and parasitology is the study of parasitic protozoa and worms.
28. Microbiologists are using genomics, the study of all of an organism’s genes, to classify bacteria, fungi, and protozoa.
29. The study of AIDS, analysis of the action of interferons, and the development of new vaccines are among the current research interests in immunology.
30. New techniques in molecular biology and electron microscopy have provided tools for advancing our knowledge of virology.
31. The development of recombinant DNA technology has helped advance all areas of microbiology.

**Microbes and Human Welfare** (pp. 15–16)

1. Microorganisms degrade dead plants and animals and recycle chemical elements to be used by living plants and animals.
2. Bacteria are used to decompose organic matter in sewage.
3. Bioremediation processes use bacteria to clean up toxic wastes.
4. Bacteria that cause diseases in insects are being used as biological controls of insect pests. Biological controls are specific for the pest and do not harm the environment.
5. Using microbes to make products such as foods and chemicals is called biotechnology.
6. Using recombinant DNA, bacteria can produce important substances such as proteins, vaccines, and enzymes.
7. In gene therapy, viruses are used to carry replacements for defective or missing genes into human cells.
8. Genetically modified bacteria are used in agriculture to protect plants from frost and insects and to improve the shelf life of produce.

**Microbes and Human Disease** (pp. 16–21)

1. Everyone has microorganisms in and on the body; these make up the normal microbiota, or flora.
2. The disease-producing properties of a species of microbe and the host’s resistance are important factors in determining whether a person will contract a disease.
3. Bacterial communities that form slimy layers on surfaces are called biofilms.
4. An infectious disease is one in which pathogens invade a susceptible host.
5. An emerging infectious disease (EID) is a new or changing disease showing an increase in incidence in the recent past or a potential to increase in the near future.

## Study Questions

Answers to the Review and Multiple Choice questions can be found by turning to the Answers tab at the back of the textbook.

### Review

- How did the idea of spontaneous generation come about?
- Briefly state the role microorganisms play in each of the following:
  - biological control of pests
  - recycling of elements
  - normal microbiota
  - sewage treatment
  - human insulin production
  - vaccine production
  - biofilms
- Into which field of microbiology would the following scientists best fit?

Researcher Who	Field
_____ a. Studies biodegradation of toxic wastes	1. Biotechnology
_____ b. Studies the causative agent of Ebola hemorrhagic fever	2. Immunology
_____ c. Studies the production of human proteins by bacteria	3. Microbial ecology
_____ d. Studies the symptoms of AIDS	4. Microbial genetics
_____ e. Studies the production of toxin by <i>E. coli</i>	5. Microbial physiology
_____ f. Studies the life cycle of <i>Cryptosporidium</i>	6. Molecular biology
_____ g. Develops gene therapy for a disease	7. Mycology
_____ h. Studies the fungus <i>Candida albicans</i>	8. Virology

- Match the microorganisms in column A to their descriptions in column B.

Column A	Column B
_____ a. Archaea	1. Not composed of cells
_____ b. Algae	2. Cell wall made of chitin
_____ c. Bacteria	3. Cell wall made of peptidoglycan
_____ d. Fungi	4. Cell wall made of cellulose; photosynthetic
_____ e. Helminths	5. Unicellular, complex cell structure lacking a cell wall
_____ f. Protozoa	6. Multicellular animals
_____ g. Viruses	7. Prokaryote without peptidoglycan cell wall

- Match the people in column A to their contribution toward the advancement of microbiology, in column B.

Column A	Column B
_____ a. Avery, MacLeod, and McCarty	1. Developed vaccine against smallpox
_____ b. Beadle and Tatum	2. Discovered how DNA controls protein synthesis in a cell
_____ c. Berg	3. Discovered penicillin

- |                              |   |
|------------------------------|---|
| _____ d. Ehrlich             | 4. Discovered that DNA can be transferred from one bacterium to another                     |
| _____ e. Fleming             | 5. Disproved spontaneous generation   |
| _____ f. Hooke               | 6. First to characterize a virus  |
| _____ g. Iwanowski           | 7. First to use disinfectants in surgical procedures  |
| _____ h. Jacob and Monod     | 8. First to observe bacteria  |
| _____ i. Jenner              | 9. First to observe cells in plant material and name them                                   |
| _____ j. Koch                | 10. Observed that viruses are filterable  |
| _____ k. Lancefield          | 11. Proved that DNA is the hereditary material  |
| _____ l. Lederberg and Tatum | 12. Proved that microorganisms can cause disease  |
| _____ m. Lister              | 13. Said living cells arise from preexisting living cells                                   |
| _____ n. Pasteur             | 14. Showed that genes code for enzymes  |
| _____ o. Stanley             | 15. Spliced animal DNA to bacterial DNA   |
| _____ p. van Leeuwenhoek     | 16. Used bacteria to produce acetone  |
| _____ q. Virchow             | 17. Used the first synthetic chemotherapeutic agent   |
| _____ r. Weizmann            | 18. Proposed a classification system for streptococci based on antigens in their cell walls |

- The genus name of a bacterium is “*erwinia*,” and the specific epithet is “*amylovora*.” Write the scientific name of this organism correctly. Using this name as an example, explain how scientific names are chosen.
- It is possible to purchase the following microorganisms in a retail store. Provide a reason for buying each.
  - Bacillus thuringiensis*
  - Saccharomyces*
- DRAW IT** Show where airborne microbes ended up in Pasteur’s experiment.



- NAME IT** What type of microorganism has a peptidoglycan cell wall, has DNA that is not contained in a nucleus, and has flagella?



## Multiple Choice

- Which of the following is a scientific name?
  - Mycobacterium tuberculosis*
  - Tubercle bacillus
- Which of the following is *not* a characteristic of bacteria?
  - are prokaryotic
  - have peptidoglycan cell walls
  - have the same shape
  - grow by binary fission
  - have the ability to move
- Which of the following is the most important element of Koch's germ theory of disease? The animal shows disease symptoms when
  - the animal has been in contact with a sick animal.
  - the animal has a lowered resistance.
  - a microorganism is observed in the animal.
  - a microorganism is inoculated into the animal.
  - microorganisms can be cultured from the animal.
- Recombinant DNA is
  - DNA in bacteria.
  - the study of how genes work.
  - the DNA resulting when genes of two different organisms are mixed.
  - the use of bacteria in the production of foods.
  - the production of proteins by genes.
- Which of the following statements is the best definition of *biogenesis*?
  - Nonliving matter gives rise to living organisms.
  - Living cells can only arise from preexisting cells.
  - A vital force is necessary for life.
  - Air is necessary for living organisms.
  - Microorganisms can be generated from nonliving matter.
- Which of the following is a beneficial activity of microorganisms?
  - Some microorganisms are used as food for humans.
  - Some microorganisms use carbon dioxide.
  - Some microorganisms provide nitrogen for plant growth.
  - Some microorganisms are used in sewage treatment processes.
  - all of the above
- It has been said that bacteria are essential for the existence of life on Earth. Which of the following is the essential function performed by bacteria?
  - control insect populations
  - directly provide food for humans
  - decompose organic material and recycle elements
  - cause disease
  - produce human hormones such as insulin
- Which of the following is an example of bioremediation?
  - application of oil-degrading bacteria to an oil spill
  - application of bacteria to a crop to prevent frost damage
  - fixation of gaseous nitrogen into usable nitrogen
  - production by bacteria of a human protein such as interferon
  - all of the above
- Spallanzani's conclusion about spontaneous generation was challenged because Lavoisier had just shown that oxygen was the vital component of air. Which of the following statements is true?
  - All life requires air.
  - Only disease-causing organisms require air.
  - Some microbes do not require air.
  - Pasteur kept air out of his biogenesis experiments.
  - Lavoisier was mistaken.
- Which of the following statements about *E. coli* is *false*?
  - E. coli* was the first disease-causing bacterium identified by Koch.
  - E. coli* is part of the normal microbiota of humans.
  - E. coli* is beneficial in human intestines.
  - A disease-causing strain of *E. coli* causes bloody diarrhea.
  - none of the above

## Critical Thinking

- How did the theory of biogenesis lead the way for the germ theory of disease?
- Even though the germ theory of disease was not demonstrated until 1876, why did Semmelweis (1840) and Lister (1867) argue for the use of aseptic techniques?
- Find at least three supermarket products made by microorganisms. (*Hint: The label will state the scientific name of the organism or include the word culture, fermented, or brewed.*)
- People once believed all microbial diseases would be controlled by the twenty-first century. Name one emerging infectious disease. List three reasons why we are identifying new diseases now.

## Clinical Applications

- The prevalence of arthritis in the United States is 1 in 100,000 children. However, 1 in 10 children in Lyme, Connecticut, developed arthritis between June and September 1973. Allen Steere, a rheumatologist at Yale University, investigated the cases in Lyme and found that 25% of the patients remembered having a skin rash during their arthritic episode and that the disease was treatable with penicillin. Steere concluded that this was a new infectious disease and did not have an environmental, genetic, or immunologic cause.
  - What was the factor that caused Steere to reach his conclusion?
  - What is the disease?
  - Why was the disease more prevalent between June and September?
- In 1864, Lister observed that patients recovered completely from simple fractures, but that compound fractures had "disastrous consequences." He knew that the application of phenol (carbolic acid) to fields in the town of Carlisle prevented cattle disease. Lister treated compound fractures with phenol, and his patients recovered without complications. How was Lister influenced by Pasteur's work? Why was Koch's work still needed?



# 2

## Chemical Principles

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We can see a tree rot and smell milk going sour, but we might not realize what is happening on a microscopic level. In both cases, microbes are conducting chemical operations. The tree rots when microorganisms decompose the wood. Milk turns sour from the production of lactic acid by bacteria. Most of the activities of microorganisms are the result of a series of chemical reactions.

Like all organisms, microorganisms use nutrients to make chemical building blocks for growth and other functions essential to life. For most microorganisms, synthesizing these building blocks requires them to break down nutrient substances and use the energy released to assemble the resulting molecular fragments into new substances.

The chemistry of microbes is one of the most important concerns of microbiologists. Knowledge of chemistry is essential to understanding what roles microorganisms play in nature, how they cause disease, how methods for diagnosing disease are developed, how the body's defenses combat infection, and how antibiotics and vaccines are produced to combat the harmful effects of microbes. The *Bacillus anthracis* bacteria in the photograph make a capsule that is not readily digested by animal cells. As discussed in the Clinical Case, these bacteria can grow in mammals by avoiding host defenses. Researchers are investigating ways to identify unique chemicals made by *B. anthracis* and other potential biological weapons in order to detect bioterrorism. To understand the changes that occur in microorganisms and the changes microbes make in the world around us, we need to know how molecules are formed and how they interact.

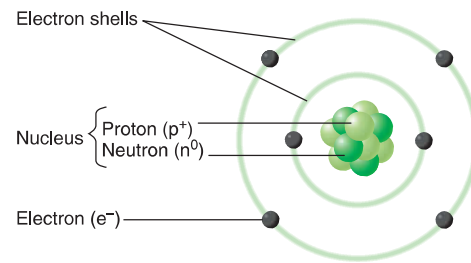
## The Structure of Atoms

### LEARNING OBJECTIVE

**2-1** Describe the structure of an atom and its relation to the physical properties of elements.

All matter—whether air, rock, or a living organism—is made up of small units called atoms. An **atom** is the smallest component of a pure substance that exhibits physical and chemical properties of that substance; an atom cannot be subdivided into smaller substances without losing its properties. Atoms interact with each other in certain combinations to form **molecules**. Living cells are made up of molecules, some of which are very complex. The science of the interaction between atoms and molecules is called **chemistry**.

Atoms are the smallest units of matter that enter into chemical reactions. Every atom has a centrally located **nucleus** and particles called **electrons** that move around the nucleus in regions called electron shells (**Figure 2.1**). The nuclei of most atoms are stable—that is, they do not change spontaneously—and nuclei do not participate in chemical reactions. The nucleus is made up of positively (+) charged particles called **protons** and uncharged (neutral) particles called **neutrons**. The nucleus, therefore, bears a net positive charge. A **charge** is a property of some subatomic particles that produces an attractive or repulsive force between them; particles of opposite charge attract each other, and particles of the same charge



**Figure 2.1 The structure of an atom.** In this simplified diagram of a carbon atom, note the central location of the nucleus. The nucleus contains six neutrons and six protons, although not all the protons are visible in this view. The six electrons move about the nucleus in regions called electron shells, shown here as circles.

**Q** What is the atomic number of this atom?

repel each other. Neutrons and protons have approximately the same weight, which is about 1840 times that of an electron. The charge on electrons is negative (−), and in all atoms the number of electrons is equal to the number of protons. Because the total positive charge of the nucleus equals the total negative charge of the electrons, each atom is electrically neutral.

The number of protons in an atomic nucleus ranges from one (in a hydrogen atom) to more than 100 (in the largest atoms known). Atoms are often listed by their **atomic number**, the number of protons in the nucleus. The total number of protons and neutrons in an atom is its approximate **atomic weight**.

### Chemical Elements

All atoms with the same number of protons behave the same way chemically and are classified as the same **chemical element**. Each element has its own name and a one- or two-letter symbol, usually derived from the English or Latin name for the element. For example, the symbol for the element hydrogen is H, and the symbol for carbon is C. The symbol for sodium is Na—the first two letters of its Latin name, *natrium*—to distinguish it from nitrogen, N, and from sulfur, S. There are 92 naturally occurring elements. However, only about 26 elements are commonly found in living things. **Table 2.1** lists some of the chemical elements found in living organisms.

Most elements have several **isotopes**—atoms with different numbers of neutrons in their nuclei. All isotopes of an element have the same number of protons in their nuclei, but their atomic weights differ because of the difference in the number of neutrons. For example, in a natural sample of oxygen, all the atoms contain eight protons. However, 99.76% of the atoms have eight neutrons, 0.04% contain nine neutrons, and the remaining 0.2% contain ten neutrons. Therefore, the three isotopes composing a natural sample of oxygen have atomic weights of 16, 17, and 18, although all will have the atomic number 8. Atomic numbers are written as a subscript to the left of an element's chemical

### Clinical Case: Drumming Up Dust

Jonathan, a 52-year-old drummer, is doing his best to ignore the cold sweat that is breaking out all over his body. He and his bandmates are performing in a local Philadelphia nightclub, and they are just about finished with the second set of the evening. Jonathan hasn't been feeling well for a while, actually; he has been feeling weak and short of breath for the last 3 days or so. Jonathan makes it to the end of the song, but the noise from the clapping and cheering audience seems to come from far away. He stands up to bow and collapses. Jonathan is admitted to a local emergency department with a mild fever and severe shaking. He is able to tell the admitting nurse that he also has had a dry cough for the last few days. The attending physician orders a chest X-ray exam and sputum culture. Jonathan is diagnosed with bilateral pneumonia caused by *Bacillus anthracis*. The attending physician is astonished by this diagnosis.

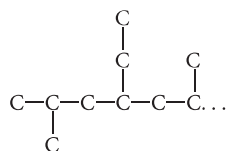
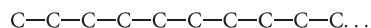
**How did Jonathan become infected by *B. anthracis*?  
Read on to find out.**

26 43 44 48



## Critical Thinking

- Here are the formulas of two detergents that have been manufactured:



Which of these would be resistant, and which would be readily degraded by microorganisms? (*Hint*: Refer to the degradation of fatty acids in Chapter 5.)

- Explain the effect of dumping untreated sewage into a pond on the eutrophication of the pond. The effect of sewage that has primary treatment? The effect of sewage that has secondary treatment? Contrast your previous answers with the effect of each type of sewage on a fast-moving river.

## Clinical Applications

- Flooding after two weeks of heavy rainfall in Tooele, Utah, preceded a high rate of diarrheal illness. *G. lamblia* was isolated from 25% of the patients. A comparison study of a town 65 miles away revealed that there was diarrheal illness in 2.9% of the 103 people interviewed. Tooele has a municipal water system and a municipal sewage treatment plant. Explain the probable cause of this epidemic and method(s) of stopping it. What would a fecal coliform test have shown?
- The bioremediation process shown in the photograph is used to remove benzene and other hydrocarbons from soil contaminated by petroleum. The pipes are used to add nitrates, phosphates, oxygen, or water. Why are each of these added? Why is it not always necessary to add bacteria?





# 28

## Applied and Industrial Microbiology

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In Chapter 27, we saw that microbes are an essential factor in many natural phenomena that make life possible on Earth. In this chapter we will look at how microorganisms are harnessed in such useful applications as the making of food and industrial products. Many of these processes—especially baking, winemaking, brewing, and cheesemaking—have origins long lost in history.

Modern civilization, with its large urban populations, could not be supported without methods of preserving food. In fact, civilization arose only after agriculture produced a year-round, stable food supply so that people were able to give up a nomadic hunting-and-gathering way of life.

In Chapter 9, we discussed industrial applications of genetically modified microorganisms that are at the cutting edge of our knowledge of molecular biology. Many of these applications are now essential to modern industry. (See the box in Chapter 1, page 3.) In this chapter we will explore the microbial production of foods, drugs, and chemicals. The Clinical Case shows the role of microbiologists in ensuring that pathogens such as *Salmonella* (in the photo) are not in foods.

## Food Microbiology

### LEARNING OBJECTIVES

- 28-1** Describe thermophilic anaerobic spoilage and flat sour spoilage by mesophilic bacteria.
- 28-2** Compare and contrast food preservation by industrial food canning, aseptic packaging, radiation, and high pressure.
- 28-3** Name four beneficial activities of microorganisms.

Many of the methods of food preservation used today were probably discovered by chance in centuries past. People in early cultures observed that dried meat and salted fish resisted decay. Nomads must have noticed that soured animal milk resisted further decomposition and was still palatable. Moreover, if the curd of the soured milk was pressed to remove moisture and allowed to ripen (in effect, cheesemaking), it was even more effectively preserved and tasted better. Farmers soon learned that if grains were kept dry, they did not become moldy.

### Foods and Disease

As more food products are being prepared at central facilities and widely distributed, it is becoming more likely that food, like municipal water supplies, might be a source of widespread disease outbreaks. To minimize the potential for disease outbreaks, communities have established local agencies whose role is to inspect dairies and restaurants. The United States Food and Drug Administration (FDA) and Department of Agriculture (USDA) also maintain a system of inspectors at ports and central processing locations. A recent development in this field has been the introduction of the **Hazard Analysis and Critical Control Point (HACCP)** system, which is intended to safeguard food “from farm to fork.” Before the introduction of the HACCP system, the primary role of governmental agencies was to conduct sampling to identify contaminated foods. Such sampling to identify contamination will still have its place, but the HACCP system is designed to prevent contamination by identifying points at which foods are most likely to be contaminated with harmful microbes. Monitoring of these control points can prevent such microbes from being introduced or, if they are

present, arrest their proliferation. For example, the HACCP system can identify steps during processing at which meats are likely to become contaminated by the animal’s intestinal contents. The HACCP system also requires monitoring of adequate temperatures to kill pathogens during processing and adequate storage temperatures to prevent their reproduction.

### Industrial Food Canning

In Chapter 7, you learned that preserving foods by heating a properly sealed container, as in home canning, is not difficult. The challenge in commercial canning is to use the right amount of heat necessary to kill spoilage organisms and dangerous microbes, such as the endospore-forming *Clostridium botulinum*, without degrading the appearance and palatability of food. Thus, much research is applied to determining the exact minimum heat treatment that will accomplish both these goals.

Industrial food canning is much more technically sophisticated than home canning (Figure 28.1). Industrially canned goods undergo **commercial sterilization** by steam under pressure in a large **retort** (Figure 28.2), which operates on the same principle as an autoclave (see Figure 7.2, page 186). Commercial sterilization is intended to destroy *C. botulinum* endospores and is not as rigorous as complete sterilization. The reasoning is that if *C. botulinum* endospores are destroyed, then any other significant spoilage or pathogenic bacteria will also be destroyed.

To ensure commercial sterilization, enough heat is applied for the **12D treatment** (12-decimal reductions, or *botulin* cook), by which a theoretical population of *C. botulinum* endospores would be decreased by 12 logarithmic cycles. (See Figure 7.1 and Table 7.2, page 183.) What this means is that if there were  $10^{12}$  (1,000,000,000,000) endospores in a can, after treatment there would be only one survivor. Because  $10^{12}$  is an improbably large population, this treatment is considered quite safe. Certain thermophilic endospore-forming bacteria have endospores that are more resistant to heat treatment than those of *C. botulinum*. However, these bacteria are obligate thermophiles and generally remain dormant at temperatures lower than about 45°C. Therefore, they are not a spoilage problem at normal storage temperatures.

### Spoilage of Canned Food

If canned foods are incubated at high temperatures, such as in a truck in the hot sun or next to a steam radiator, the thermophilic bacteria that often survive commercial sterilization can germinate and grow. **Thermophilic anaerobic spoilage** is therefore a fairly common cause of spoilage in low-acid canned foods. The can usually swells from gas, and the contents have a lowered pH and a sour odor. A number of thermophilic species of *Clostridium* can cause this type of spoilage. When thermophilic spoilage occurs but the can is not swollen by gas production, the spoilage is termed **flat sour spoilage**. This type

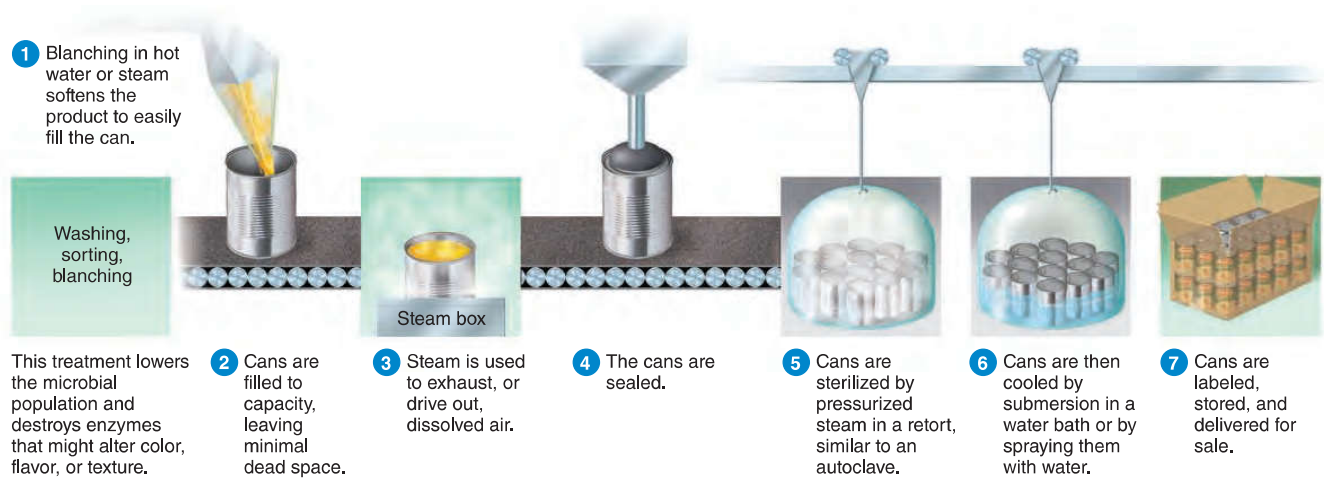
### Clinical Case: Dr. Chang and the Chocolate Factory

Dr. Derrick Chang of the CDC is alerted by PulseNet, the national molecular subtyping network for foodborne disease surveillance. PulseNet has identified an increase of genetically identical *Salmonella typhimurium* in the United States. This increase shows 120 isolates from 23 states in the last 60 days.

**What is causing this outbreak? Read on to find out.**

**800 802 807 811 813 815**





**Figure 28.1** The commercial sterilization process in industrial canning.

**Q** How does commercial sterilization differ from complete sterilization?

of spoilage is caused by thermophilic organisms such as *Geobacillus stearothermophilus* (ste-rō-thēr-mă'fil-us), which is found in the starch and sugars used in food preparation. Many industries have standards for the numbers of such thermophilic bacteria permitted in raw materials. Both types of spoilage occur only when the cans are stored at higher than normal temperatures, which permits the growth of bacteria whose endospores are not destroyed by normal processing.

Mesophilic bacteria can spoil canned foods if the food is underprocessed or if the can leaks. Underprocessing is more likely to result in spoilage by endospore formers; the presence of non-endospore-forming bacteria strongly suggests that the can leaks. Leaking cans are often contaminated during the cooling of cans after processing by heat. The hot cans are sprayed with cooling water or passed through a trough filled with water. As the can cools, a vacuum is formed inside, and external water can be sucked through a leak past the heat-softened sealant in the crimped lid (Figure 28.3). Contaminating bacteria in the cooling water are drawn into the can with the water. Spoilage from underprocessing or can leakage is likely to produce odors of putrefaction, at least in high-protein foods, and occurs at normal storage temperatures. In such types of spoilage, there is always the potential that botulinal bacteria will be present.

Some acidic foods, such as tomatoes or preserved fruits, are preserved by processing temperatures of 100°C or lower. The reasoning is that the only spoilage organisms that will grow in such acidic foods are easily killed by even 100°C temperatures. Primarily, these would be molds, yeasts, and certain vegetative bacteria.

Occasional problems in acidic foods develop from a few microorganisms that are both heat-resistant and acid-tolerant.

Examples of heat-resistant fungi are the mold *Byssoschlamys fulva* (bis-sō-klam'is ful'vā), which produces a *heat-resistant ascospore*, and a few molds, especially species of *Aspergillus*, that sometimes produce specialized resistant bodies called *sclerotia*. A spore-forming bacterium, *Bacillus coagulans* (kō-ag'ū-lanz), is unusual in that it is capable of growth at a pH of almost 4.0. Table 28.1 lists types of spoilage in low- and medium-acid foods.

### Aseptic Packaging

The use of **aseptic packaging** to preserve food has been increasing. Packages are usually made of some material that cannot



**Figure 28.2** Commercial canning retorts. These are much larger than the sterilizing autoclaves used in most microbiology laboratories or hospitals.

**Q** Is there any difference in principle between a canning retort and a hospital autoclave?



**Figure 28.3 The construction of a metal can.** Notice the seam construction, which was introduced about 1904. During cooling after sterilization (see Figure 28.1, step 6), the vacuum formed in the can may actually force contaminating organisms into the can along with water.

**Q** Why isn't the can sealed before it is placed in the steam box?

tolerate conventional heat treatment, such as laminated paper or plastic. The packaging materials come in continuous rolls that are fed into a machine that sterilizes the material with a hot hydrogen peroxide solution, sometimes aided by ultraviolet (UV) light (Figure 28.4). Metal containers can be sterilized with superheated steam or other high-temperature methods. High-energy electron

beams can also be used to sterilize the packaging materials. While still in the sterile environment, the material is formed into packages, which are then filled with liquid foods that have been conventionally sterilized by heat. The filled package is not sterilized after it is sealed.



**Figure 28.4 Aseptic packaging.** Rolls of packaging material in foreground, filled packages at right center.

**Q** Why has the use of this procedure been increasing in recent years?

### Clinical Case

Dr. Chang initiates a case-control study with representatives of the state health departments that had reported *S. typhimurium* infections. Fifteen items, suspected as possible vehicles of infection on the basis of the individual case investigations, are listed. State officials determine whether each suspect item was used or consumed by the infected person within the 3 days before onset of illness. The family of each patient identifies two neighborhood controls, of the same age and gender as the patient. Controls were asked the same questions as patients, except that they were questioned about the use or consumption of the 15 suspect items during the previous month. Some of the data collected are shown in the table.

Foil-Wrapped Chocolate Balls	Cases	Controls
Ate	38	12
Did not eat	7	79

**Calculate the relative risk for this food item.**  
(Hint: See page 721)

800 802 807 811 813 815

**TABLE 28.1** Common Types of Spoilage in Low-Acid and Medium-Acid Canned Foods (pH above 4.5)

Type of Spoilage	Indications of Spoilage	
	Appearance of Can	Contents of Can
Flat sour ( <i>Geobacillus stearothermophilus</i> )	Can not swollen	Appearance not usually altered; pH markedly lowered; sour; may have slightly abnormal odor; sometimes cloudy liquid
Thermophilic anaerobic ( <i>Thermoanaerobacterium thermosaccharolyticum</i> )	Swollen	Fermented, sour, cheesy, or butyric acid odor
Putrefactive anaerobic ( <i>Clostridium sporogenes</i> ; possibly <i>C. botulinum</i> )	Swollen	May be partially digested; pH slightly above normal; typical putrid odor

## Radiation and Industrial Food Preservation

It has long been recognized that irradiation is lethal to microorganisms; in fact, a patent was issued in Great Britain in 1905 for the use of ionizing radiation to improve the condition of foodstuffs. X rays were specifically suggested in 1921 as a way to inactivate the larvae in pork that are the cause of trichinellosis. Ionizing irradiation inhibits DNA synthesis and effectively prevents microorganisms, insects, and plants from reproducing. The ionizing irradiation is usually X rays or the gamma rays produced by radioactive cobalt-60. Up to certain energy levels, high energy electrons produced by electron accelerators are also used. The main practical difference is in penetration capabilities. These sources inactivate the target organisms and do *not* induce radioactivity in the food or packaging material. The relative doses of radiation needed to kill various organisms are presented in [Table 28.2](#). Radiation is measured in *Grays*, named for an early radiologist—often in terms of thousands of Grays, abbreviated as kGy.

- *Low doses of irradiation (less than 1 kGy)* are used for killing insects (disinfestation) and inhibiting sprouting, as in stored potatoes. Similarly, it can delay ripening of fruits during storage.

- *Pasteurizing doses (1 to 10 kGy)* can be used on meats and poultry to eliminate or critically reduce the numbers of specific bacterial pathogens.
- *High doses (more than 10 kGy)* are used to sterilize, or at least greatly lower, the bacterial populations in many spices. Spices are often contaminated with 1 million or more bacteria per gram, although these are not considered to be normally hazardous to health.

A specialized use of irradiation has been to sterilize meats eaten by American astronauts, and a few health facilities have selectively used irradiation to sterilize foods ingested by immunocompromised patients. Millions of implanted medical devices, such as pacemakers, have been irradiated. Irradiated food is marked in the United States with a radura symbol ([Figure 28.5](#)) and a printed notice. Unfortunately, this symbol has often been interpreted as a warning rather than the description of an approved processing treatment or preservative. In fact, irradiated foods are not radioactive; consider that the X-ray table in a hospital does not become radioactive from repeated daily exposure to ionizing radiation. Recently, the FDA has allowed, upon special approval, substitution of language such as “pasteurization” rather than “irradiation.”

When deep penetration is a requirement, the preferred method for irradiation is gamma rays produced by cobalt-60.

**TABLE 28.2** Approximate Doses of Radiation Needed to Kill Various Organisms (Prions Are Not Affected)

Organisms	Dose (kGy)*
Higher animals (whole body)	0.005–0.1
Insects	0.01–1
Non-endospore-forming bacteria	0.5–10
Bacterial endospores	10–50
Viruses	10–200

\*Gray is a measure of ionizing irradiation; kGy is 1000 Grays.

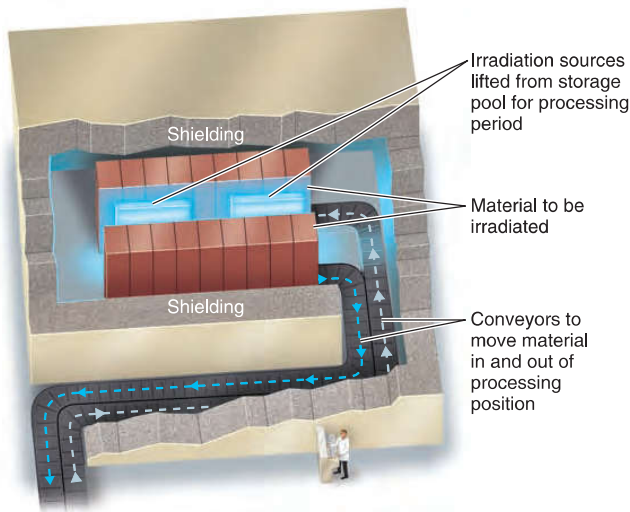
Source: J. Farkas, “Physical Methods of Food Preservation,” in *Food Microbiology: Fundamentals and Frontiers*, 2d ed., M.P. Doyle et al. (eds) (Washington, DC: ASM Press, 2001).



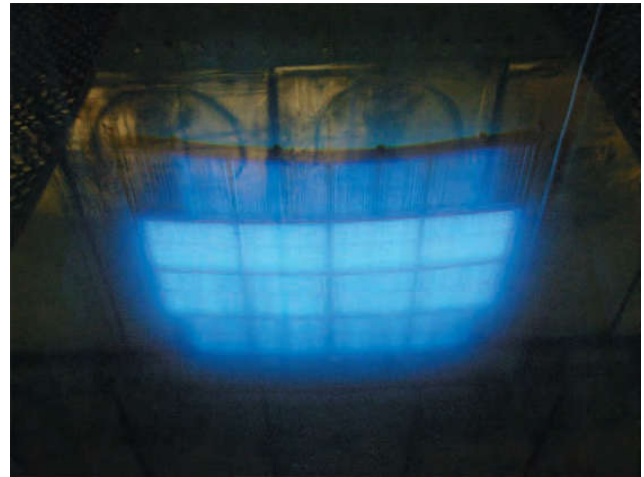
**Figure 28.5 Irradiation logo.** This logo, the international radura symbol, indicates that a food has received irradiation treatment.

**Q** Is irradiation the same as a chemical additive?





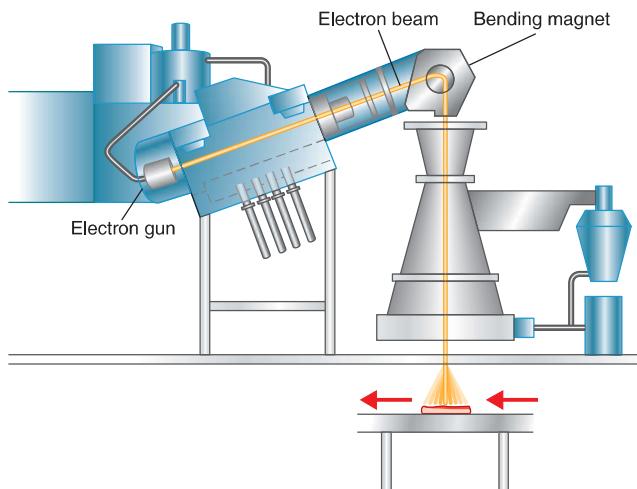
(a) An irradiation facility, showing the path of the material to be irradiated



(b) The irradiation source is submerged in the storage pool. The blue glow is Cerenkov radiation caused by charged particles exceeding the speed of light in water.

**Figure 28.6** A gamma-ray irradiation facility.

**Q** Can microwaves be used to sterilize foods?



**Figure 28.7** Electron-beam accelerator. These machines generate an electron stream that is accelerated down a long tube by electromagnets of the opposite charge. In the drawing, the electron beam is bent by a “bending magnet.” This serves to filter out electrons of unwanted energy levels, providing a beam of uniform energy. The vertical beam is swept back and forth over the target as it is moved past the beam. The penetrating power of the beam is limited: if the target substance is expressed as an equivalent thickness of water, the maximum is about 3.9 cm (1.5 in). In contrast, X rays will penetrate about 23 cm (9 in).

**Q** Are high-energy electrons ionizing radiation?

However, this type of treatment requires several hours of exposure in isolation behind protective walls (**Figure 28.6**).

High-energy electron accelerators (**Figure 28.7**) are much faster and sterilize in a few seconds, but this treatment has low penetrating power and is suitable only for sliced meats, bacon, or similar thin products. Also, plasticware used in microbiology is usually sterilized in this way. Another recent application is to irradiate mail to kill possible bioterrorism agents that it might contain, such as anthrax endospores.

### High-Pressure Food Preservation

A recent development in food preservation (pascalation) has been the use of a high-pressure processing technique. Prewrapped foods such as fruits, deli meats, and precooked chicken strips are submerged into tanks of pressurized water. The pressure can reach 87,000 pounds per square inch (psi)—which has been compared to the equivalent of about three elephants standing on a dime. This process kills many bacteria, such as *Salmonella*, *Listeria*, and pathogenic strains of *E. coli*, by disrupting many cellular functions. It also kills nonpathogenic microorganisms that tend to shorten the shelf life of such products.

Because the process does not require additives, it does not require regulatory approval. It has the advantage of preserving colors and tastes of foods better than many other methods and does not provoke the concerns of irradiation.

# GLOSSARY

**9 + 2 array** Attachment of microtubules in eukaryotic flagella and cilia; 9 pairs of microtubules plus two microtubules.

**12D treatment** A sterilization process that would result in a decrease of the number of *Clostridium botulinum* endospores by 12 logarithmic cycles.

**ABO blood group system** The classification of red blood cells based on the presence or absence of A and B carbohydrate antigens.

**abscess** A localized accumulation of pus.

**A-B toxin** Bacterial exotoxins consisting of two polypeptides.

**acellular vaccine** A vaccine consisting of antigenic parts of cells.

**acetyl group**  

$$\begin{array}{c} \text{O} \\ || \\ \text{H}_3\text{C}-\text{C}- \end{array}$$

**acid** A substance that dissociates into one or more hydrogen ions ( $\text{H}^+$ ) and one or more negative ions.

**acid-fast stain** A differential stain used to identify bacteria that are not decolorized by acid-alcohol.

**acidic dye** A salt in which the color is in the negative ion; used for negative staining.

**acidophile** A bacterium that grows below pH 4.

**acquired immunodeficiency** The inability, obtained during the life of an individual, to produce specific antibodies or T cells, due to drugs or disease.

**activated macrophage** A macrophage that has increased phagocytic ability and other functions after exposure to mediators released by T cells after stimulation by antigens.

**activated sludge system** A process used in secondary sewage treatment in which batches of sewage are held in highly aerated tanks; to ensure the presence of microbes efficient in degrading sewage, each batch is inoculated with portions of sludge from a previous batch.

**activation energy** The minimum collision energy required for a chemical reaction to occur.

**active site** A region on an enzyme that interacts with the substrate.

**active transport** Net movement of a substance across a membrane against a concentration gradient; requires the cell to expend energy.

**acute disease** A disease in which symptoms develop rapidly but last for only a short time.

**acute-phase proteins** Serum proteins whose concentration changes by at least 25% during inflammation.

**adaptive immunity** The ability, obtained during the life of the individual, to produce specific antibodies and T cells.

**adenosarcoma** Cancer of glandular epithelial tissue.

**adenosine diphosphate (ADP)** The substance formed when ATP is hydrolyzed and energy is released.

**adenosine triphosphate (ATP)** An important intracellular energy source.

**adherence** Attachment of a microbe or phagocyte to another's plasma membrane or other surface.

**adhesin** A carbohydrate-specific binding protein that projects from prokaryotic cells; used for adherence, also called a ligand.

**adjuvant** A substance added to a vaccine to increase its effectiveness.

**aerobe** An organism requiring molecular oxygen ( $\text{O}_2$ ) for growth.

**aerobic respiration** Respiration in which the final electron acceptor in the electron transport chain is molecular oxygen ( $\text{O}_2$ ).

**aerotolerant anaerobe** An organism that does not use molecular oxygen ( $\text{O}_2$ ) but is not affected by its presence.

**aflatoxin** A carcinogenic toxin produced by *Aspergillus flavus*.

**agar** A complex polysaccharide derived from a marine alga and used as a solidifying agent in culture media.

**agglutination** A joining together or clumping of cells.

**agranulocyte** A leukocyte without visible granules in the cytoplasm; includes monocytes and lymphocytes.

**alarmone** A chemical signal that promotes a cell's response to environmental stress.

**alcohol** An organic molecule with the functional group—OH.

**alcohol fermentation** A catabolic process, beginning with glycolysis, that produces ethyl alcohol to reoxidize NADH.

**aldehyde** An organic molecule with the functional group



**alga** (plural: **algae**) A photosynthetic eukaryote; may be unicellular, filamentous, or multicellular but lack the tissues found in plants.

**algal bloom** An abundant growth of microscopic algae producing visible colonies in nature.

**algin** A sodium salt of mannuronic acid ( $\text{C}_6\text{H}_8\text{O}_6$ ); found in brown algae.

**allergen** An antigen that evokes a hypersensitivity response.

**allergy** See hypersensitivity.

**allograft** A tissue graft that is not from a genetically identical donor (i.e., not from self or an identical twin).

**allosteric inhibition** The process in which an enzyme's activity is changed because of binding to the allosteric site.

**allosteric site** The site on an enzyme at which a noncompetitive inhibitor binds.

**allylamines** Antifungal agents that interfere with sterol synthesis.

**amanitin** A polypeptide toxin produced by *Amanita* spp., inhibits RNA polymerase.

**Ames test** A procedure using bacteria to identify potential carcinogens.

**amination** The addition of an amino group.

**amino acid** An organic acid containing an amino group and a carboxyl group. In alpha-amino acids the amino and carboxyl groups are attached to the same carbon atom called the alpha-carbon.

**aminoglycoside** An antibiotic consisting of amino sugars and an aminocyclitol ring; for example, streptomycin.

**amino group**  $-\text{NH}_2$ .

**ammonification** The release of ammonia from nitrogen-containing organic matter by the action of microorganisms.

**amphibolic pathway** A pathway that is both anabolic and catabolic.

**amphitrichous** Having flagella at both ends of a cell.

**anabolism** All synthesis reactions in a living organism; the building of complex organic molecules from simpler ones.

**anaerobe** An organism that does not require molecular oxygen ( $\text{O}_2$ ) for growth.

**anaerobic respiration** Respiration in which the final electron acceptor in the electron transport chain is an inorganic molecule other than molecular oxygen ( $\text{O}_2$ ); for example, a nitrate ion or  $\text{CO}_2$ .

**anaerobic sludge digester** Anaerobic digestion used in secondary sewage treatment.

**anal pore** A site in certain protozoa for elimination of waste.

**analytical epidemiology** Comparison of a diseased group and a healthy group to determine the cause of the disease.

**anamnesic response** See memory response.

**anamorph** Ascomycete fungi that have lost the ability to reproduce sexually; the asexual stage of a fungus.

**anaphylaxis** A hypersensitivity reaction involving IgE antibodies, mast cells, and basophils.

**Angstrom ( $\text{\AA}$ )** A unit of measurement equal to  $10^{-10}$  m, or 0.1 nm.

**Animalia** The kingdom composed of multicellular eukaryotes lacking cell walls.

**anion** An ion with a negative charge.

**anoxygenic** Not producing molecular oxygen; typical of cyclic photophosphorylation.

**antagonism** Active opposition; (1) When two drugs are less effective than either one alone. (2) Competition among microbes.

**antibiogram** Report of antibiotic susceptibility of a bacterium.

**antibiotic** An antimicrobial agent, usually produced naturally by a bacterium or fungus.

**antibody** A protein produced by the body in response to an antigen, and capable of combining specifically with that antigen.

**antibody-dependent cell-mediated cytotoxicity (ADCC)** The killing of antibody-coated cells by natural killer cells and leukocytes.

**antibody titer** The amount of antibody in serum.

**anticodon** The three nucleotides by which a tRNA recognizes an mRNA codon.

**antigen** Any substance that causes antibody formation; also called immunogen.

**antigen-antibody complex** The combination of an antigen with the antibody that is specific for it; the basis of immune protection and many diagnostic tests.

**antigen-binding sites** A site on an antibody that binds to an antigenic determinant.

**antigenic determinant** A specific region on the surface of an antigen against which antibodies are formed; also called epitope.

**antigenic drift** A minor variation in the antigenic makeup of influenza viruses that occurs with time.

**antigenic shift** A major genetic change in influenza viruses causing changes in H and N antigens.

**antigenic variation** Changes in surface antigens that occur in a microbial population.

**antigen-presenting cell (APC)** A macrophage, dendritic cell, or B cell that engulfs an antigen and presents fragments to T cells.

**anti-human immune serum globulin (anti-HISG)** An antibody that reacts specifically with human antibodies.

**antimetabolite** A competitive inhibitor.

**antimicrobial peptide** An antibiotic that is bactericidal and has a broad spectrum of activity; *see* bacteriocin.

**antisense DNA** DNA that is complementary to the DNA encoding a protein; the antisense RNA transcript will hybridize with the mRNA encoding the protein and inhibit synthesis of the protein.

**antisense strand (– strand)** Viral RNA that cannot act as mRNA.

**antiseptis** A chemical method for disinfection of the skin or mucous membranes; the chemical is called an antiseptic.

**antiserum** A blood-derived fluid containing antibodies.

**antitoxin** A specific antibody produced by the body in response to a bacterial exotoxin or its toxoid.

**antiviral protein (AVP)** A protein made in response to interferon that blocks viral multiplication.

**apoenzyme** The protein portion of an enzyme, which requires activation by a coenzyme.

**apoptosis** The natural programmed death of a cell; the residual fragments are disposed of by phagocytosis.

**aquatic microbiology** The study of microorganisms and their activities in natural waters.

**arbuscule** Fungal mycelia in plant root cells.

**archaea** Domain of prokaryotic cells lacking peptidoglycan; one of the three domains.

**arthroconidia** An asexual fungal spore formed by fragmentation of a septate hypha.

**Arthus reaction** Inflammation and necrosis at the site of injection of foreign serum, due to immune complex formation.

**artificially acquired active immunity** The production of antibodies by the body in response to a vaccination.

**artificially acquired passive immunity** The transfer of humoral antibodies formed by one individual to a susceptible individual, accomplished by the injection of antiserum.

**artificial selection** Choosing one organism from a population to grow because of its desirable traits.

**ascospore** A sexual fungal spore produced in an ascus, formed by the ascomycetes.

**ascus** A saclike structure containing ascospores; found in the ascomycetes.

**asepsis** The absence of contamination by unwanted organisms.

**aseptic packaging** Commercial food preservation by filling sterile containers with sterile food.

**aseptic surgery** Techniques used in surgery to prevent microbial contamination of the patient.

**aseptic techniques** Laboratory techniques used to minimize contamination.

**asexual spore** A reproductive cell produced by mitosis and cell division (eukaryotes) or binary fission (actinomycetes).

**atom** The smallest unit of matter that can enter into a chemical reaction.

**atomic force microscopy** *See* scanned-probe microscopy.

**atomic number** The number of protons in the nucleus of an atom.

**atomic weight** The total number of protons and neutrons in the nucleus of an atom.

**atrichous** Bacteria that lack flagella.

**attenuated vaccine** A vaccine containing live, attenuated (weakened) microorganisms.

**autoclave** Equipment for sterilization by steam under pressure, usually operated at 15 psi and 121°C.

**autograft** A tissue graft from one's self.

**autoimmune disease** Damage to one's own organs due to action of the immune system.

**autotroph** An organism that uses carbon dioxide (CO<sub>2</sub>) as its principal carbon source. chemoautotroph, photoautotroph.

**auxotroph** A mutant microorganism with a nutritional requirement that is absent in the parent.

**axial filament** The structure for motility found in spirochetes; also called endoflagellum.

**azole** Antifungal agents that interfere with sterol synthesis.

**bacillus** (plural: **bacilli**) (1) Any rod-shaped bacterium. (2) When written as a genus (*Bacillus*) refers to rod-shaped, endospore-forming, facultatively anaerobic, gram-positive bacteria.

**bacteremia** A condition in which there are bacteria in the blood.

**bacteria** Domain of prokaryotic organisms, characterized by peptidoglycan cell walls; **bacterium** (singular) when referring to a single organism.

**bacterial growth curve** A graph indicating the growth of a bacterial population over time.

**bactericide** A substance capable of killing bacteria.

**bacteriocin** An antimicrobial peptide produced by bacteria that kills other bacteria.

**bacteriochlorophyll** A photosynthetic pigment that transfers electrons for photophosphorylation; found in anoxygenic photosynthetic bacteria.

**bacteriology** The scientific study of prokaryotes, including bacteria and archaea.

**bacteriophage (phage)** A virus that infects bacterial cells.

**bacteriostasis** A treatment capable of inhibiting bacterial growth.

**base** A substance that dissociates into one or more hydroxide ions (OH<sup>–</sup>) and one or more positive ions.

**base pairs** The arrangement of nitrogenous bases in nucleic acids based on hydrogen bonding; in DNA, base pairs are A-T and G-C; in RNA, base pairs are A-U and G-C.

**base substitution** The replacement of a single base in DNA by another base, causing a mutation; also called point mutation.

**basic dye** A salt in which the color is in the positive ion; used for bacterial stains.

**basidiospore** A sexual fungal spore produced in a basidium, characteristic of the basidiomycetes.

**basidium** A pedestal that produces basidiospores; found in the basidiomycetes.

**basophil** A granulocyte (leukocyte) that readily takes up basic dye and is not phagocytic; has receptors for IgE Fc regions.

**batch production** An industrial process in which cells are grown for a period of time after which the product is collected.

**B cell** A type of lymphocyte; differentiates into antibody-secreting plasma cells and memory cells.

**BCG vaccine** A live, attenuated strain of *Mycobacterium bovis* used to provide immunity to tuberculosis.

**beer** Alcoholic beverage produced by fermentation of starch.

**benthic zone** The sediment at the bottom of a body of water.

**Bergey's Manual** *Bergey's Manual of Systematic Bacteriology*, the standard taxonomic reference on bacteria; also refers to *Bergey's Manual of Determinative Bacteriology*, the standard laboratory identification reference on bacteria.



**purple sulfur bacteria** Gammaproteobacteria; strictly anaerobic and phototrophic; use reduced sulfur compounds as electron donors for CO<sub>2</sub> fixation.

**pus** An accumulation of dead phagocytes, dead bacterial cells, and fluid.

**pustule** A small pus-filled elevation of skin.

**pyocyanin** A blue-green pigment produced by *Pseudomonas aeruginosa*.

**pyrimidines** The class of nucleic acid bases that includes uracil, thymine, and cytosine.

**quaternary ammonium compound (quat)** A cationic detergent with four organic groups attached to a central nitrogen atom; used as a disinfectant.

**quorum sensing** The ability of bacteria to communicate and coordinate behavior via signaling molecules.

**R** Used to represent nonfunctional groups of a molecule. *See also* resistance factor.

**rapid diagnostic test (RDT)** A test that allows diagnosis of a disease within a few minutes.

**rapid identification methods** Bacterial identification tools that perform several biochemical tests simultaneously.

**rapid plasma reagin (RPR) test** A serological test for syphilis.

**r-determinant** A group of genes for antibiotic resistance carried on R factors.

**RecA** Catalyzes joining of DNA strands, facilitates recombination of DNA.

**receptor** An attachment for a pathogen on a host cell.

**receptor-mediated endocytosis** A type of pinocytosis in which molecules bound to proteins on the plasma membrane are taken in by infolding of the membrane.

**recipient cell** A cell that receives DNA from a donor cell during genetic recombination.

**recombinant DNA (rDNA)** A DNA molecule produced by combining DNA from two different sources.

**recombinant DNA (rDNA) technology** Manufacturing and manipulating genetic material in vitro; also called genetic engineering.

**recombinant vaccine** A vaccine made by recombinant DNA techniques.

**redia** A trematode larval stage that reproduces asexually to produce cercariae.

**redox reaction** *See* oxidation-reduction.

**red tide** A bloom of planktonic dinoflagellates.

**reducing medium** A culture medium containing ingredients that will remove dissolved oxygen from the medium to allow the growth of anaerobes.

**reduction** The addition of electrons to a molecule.

**refractive index** The relative velocity with which light passes through a substance.

**relative risk** A comparison of the risk of disease in two groups.

**rennin** An enzyme that forms curds as part of any dairy fermentation product; originally from calves' stomachs, now produced by molds and bacteria.

**replica plating** A method of inoculating a number of solid minimal culture media from an original plate to produce the same pattern of colonies on each plate.

**replication fork** The point where DNA strands separate and new strands will be synthesized.

**repression** The process by which a repressor protein can stop the synthesis of a protein.

**repressor** A protein that binds to the operator site to prevent transcription.

**reservoir of infection** A continual source of infection.

**resistance** The ability to ward off diseases through innate and adaptive immunity.

**resistance (R) factor** A bacterial plasmid carrying genes that determine resistance to antibiotics.

**resistance transfer factor (RTF)** A group of genes for replication and conjugation on the R factor.

**resolution** The ability to distinguish fine detail with a magnifying instrument; also called resolving power.

**respiration** A series of redox reactions in a membrane that generates ATP; the final electron acceptor is usually an inorganic molecule.

**restriction enzyme** An enzyme that cuts double-stranded DNA at specific sites between nucleotides.

**reticulate body** The intracellular growing stage of chlamydiae.

**reticuloendothelial system** *See* mononuclear phagocytic system.

**retort** A device for commercially sterilizing canned food by using steam under pressure; operates on the same principle as an autoclave but is much larger.

**reverse genetics** Genetic analysis that begins with a piece of DNA and proceeds to find out what it does.

**reverse transcriptase** An RNA-dependent DNA polymerase; an enzyme that synthesizes a complementary DNA from an RNA template.

**reversible reaction** A chemical reaction in which the end-products can readily revert to the original molecules.

**RFLP** Restriction fragment length polymorphism; a fragment resulting from restriction-enzyme digestion of DNA.

**Rh factor** An antigen on red blood cells of rhesus monkeys and most humans; possession makes the cells Rh<sup>+</sup>.

**rhizine** A rootlike hypha that anchors a fungus to a surface.

**ribonucleic acid (RNA)** The class of nucleic acids that comprises messenger RNA, ribosomal RNA, and transfer RNA.

**ribose** A five-carbon sugar that is part of ribonucleotide molecules and RNA.

**ribosomal RNA (rRNA)** The type of RNA molecule that forms ribosomes.

**ribosomal RNA (rRNA) sequencing** Determination of the order of nucleotide bases in rRNA.

**ribosome** The site of protein synthesis in a cell, composed of RNA and protein.

**ribotyping** Classification or identification of bacteria based on rRNA genes.

**ribozyme** An enzyme consisting of RNA that specifically acts on strands of RNA to remove introns and splice together the remaining exons.

**ring stage** A young *Plasmodium* trophozoite that looks like a ring in a red blood cell.

**RNAi** RNA interference; stops gene expression at transcription by using a short interfering RNA to make double-stranded RNA.

**RNA-induced silencing complex (RISC)** A complex consisting of a protein and siRNA or miRNA that binds complementary mRNA, preventing transcription of the mRNA.

**RNA primer** A short strand of RNA used to start synthesis of the lagging strand of DNA, and to start the polymerase chain reaction.

**root nodule** A tumorlike growth on the roots of certain plants containing symbiotic nitrogen-fixing bacteria.

**rotating biological contactor** A method of secondary sewage treatment in which large disks are rotated while partially submerged in a sewage tank exposing sewage to microorganisms and aerobic conditions.

**rough ER** Endoplasmic reticulum with ribosomes on its surface.

**roundworm** An animal belonging to the phylum Nematoda.

**S (Svedberg unit)** Notes the relative rate of sedimentation during ultra-high speed centrifugation.

**salt** A substance that dissolves in water to cations and anions, neither of which is H<sup>+</sup> or OH<sup>-</sup>.

**sanitization** The removal of microbes from eating utensils and food preparation areas.

**saprophyte** An organism that obtains its nutrients from dead organic matter.

**sarcina** (plural: **sarcinae**) (1) A group of eight bacteria that remain in a packet after dividing. (2) When written as a genus, refers to gram-positive, anaerobic cocci.

**saturation** (1) The condition in which the active site on an enzyme is occupied by the substrate or product at all times. (2) In a fatty acid, having no double bonds.

**saxitoxin** A neurotoxin produced by some dinoflagellates.

**scanned-probe microscopy** Microscopic technique used to obtain images of molecular shapes, to characterize chemical properties, and to determine temperature variations within a specimen.

**scanning acoustic microscope (SAM)** A microscope that uses high-frequency ultrasound waves to penetrate surfaces.

**scanning electron microscope (SEM)** An electron microscope that provides three-dimensional views of the specimen magnified 1000–10,000×.

**scanning tunneling microscopy** *See* scanned-probe microscopy.

**schizogony** The process of multiple fission, in which one organism divides to produce many daughter cells.

**scientific nomenclature** *See* binomial nomenclature.

**sclerotia** The compact mass of hardened mycelia of the fungus *Claviceps purpurea* that fills infected rye flowers; produces the toxin ergot.

**scolex** The head of a tapeworm, containing suckers and possibly hooks.

**secondary infection** An infection caused by an opportunistic microbe after a primary infection has weakened the host's defenses.

**secondary metabolite** A product of an industrial cell population produced after the microorganism has largely completed its period of rapid growth and is in a stationary phase of the growth cycle. *See also* primary metabolite.

**secondary response** *See* memory response.

**secondary sewage treatment** Biological degradation of the organic matter in wastewater following primary treatment.

**secretory vesicle** A membrane-enclosed sac produced by the ER; transports synthesized material into cytoplasm.

**selective medium** A culture medium designed to suppress the growth of unwanted microorganisms and encourage the growth of desired ones.

**selective permeability** The property of a plasma membrane to allow certain molecules and ions to move through the membrane while restricting others.

**selective toxicity** The property of some antimicrobial agents to be toxic for a microorganism and nontoxic for the host.

**self** Host tissue.

**semiconservative replication** The process of DNA replication in which each double-stranded DNA molecule contains one original strand and one new strand.

**sense codon** A codon that codes for an amino acid.

**sense strand (+ strand)** Viral RNA that can act as mRNA.

**sensitivity** Percentage of positive samples correctly detected by a diagnostic test.

**sentinel animal** An organism in which changes can be measured to assess the extent of environmental contamination and its implication for human health.

**sepsis** The presence of a toxin or pathogenic organism in blood and tissue.

**septate hypha** A hypha consisting of uninucleate cell-like units.

**septicemia** The proliferation of pathogens in the blood, accompanied by fever; sometimes causes organ damage.

**septic shock** A sudden drop in blood pressure induced by bacterial toxins.

**septum** A cross-wall in a fungal hypha.

**serial dilution** The process of diluting a sample several times.

**seroconversion** A change in a person's response to an antigen in a serological test.

**serological testing** Techniques for identifying a microorganism based on its reaction with antibodies.

**serology** The branch of immunology that studies blood serum and antigen-antibody reactions in vitro.

**serotype** *See* serovar.

**serovar** A variation within a species; also called serotype.

**serum** The liquid remaining after blood plasma is clotted; contains antibodies (immunoglobulins).

**sexual dimorphism** The distinctly different appearance of adult male and female organisms.

**sexual spore** A spore formed by sexual reproduction.

**Shiga toxin** An exotoxin produced by *Shigella dysenteriae* and enterohemorrhagic *E. coli*.

**shock** Any life-threatening loss of blood pressure. *See also* septic shock.

**short tandem repeats (STRs)** Repeating sequences of 2- to 5-nucleotides.

**shotgun sequencing** A technique for determining the nucleotide sequence in an organism's genome.

**shuttle vector** A plasmid that can exist in several different species; used in genetic engineering.

**siderophore** Bacterial iron-binding proteins.

**sign** A change due to a disease that a person can observe and measure.

**simple stain** A method of staining microorganisms with a single basic dye.

**singlet oxygen** Highly reactive molecular oxygen ( $O_2^{\cdot-}$ ).

**siRNA** Small interfering RNA; An intermediate in the RNAi process in which the long double-stranded RNA has been cut up into short (~21 nucleotides) double-stranded RNA.

**site-directed mutagenesis** Techniques used to modify a gene in a specific location to produce the desired polypeptide.

**slide agglutination test** A method of identifying an antigen by combining it with a specific antibody on a slide.

**slime layer** A glycocalyx that is unorganized and loosely attached to the cell wall.

**sludge** Solid matter obtained from sewage.

**smear** A thin film of material containing microorganisms, spread over the surface of a slide.

**smooth ER** Endoplasmic reticulum without ribosomes.

**SNP** Single nucleotide polymorphism (pronounced "snip"). Single base-pair variations in the genomes of a population, found in at least 1% of the population.

**snRNP** Small nuclear ribonucleoprotein (pronounced "snurp"). Short RNA transcript plus protein that combines with pre-mRNA to remove introns and join exons together.

**solute** A substance dissolved in another substance.

**solvent** A dissolving medium.

**Southern blotting** A technique that uses DNA probes to detect the presence of specific DNA in restriction fragments separated by electrophoresis.

**specialized transduction** The process of transferring a piece of cell DNA adjacent to a prophage to another cell.

**species** The most specific level in the taxonomic hierarchy. *See also* bacterial species; eukaryotic species; viral species.

**specific epithet** The second or species name in a scientific binomial. *See also* species.

**specificity** Percentage of false positive results given by a diagnostic test.

**spectrum of microbial activity** The range of distinctly different types of microorganisms affected by an antimicrobial drug; a wide range is referred to as a broad spectrum of activity.

**spheroplast** A gram-negative bacterium treated to damage the cell wall, resulting in a spherical cell.

**spicule** One of two external structures on the male roundworm used to guide sperm.

**spike** A carbohydrate-protein complex that projects from the surface of certain viruses.

**spiral** *See* spirillum and spirochete.

**spirillum** (plural: **spirilla**) (1) A helical or corkscrew-shaped bacterium. (2) When written as a genus, refers to aerobic, helical bacteria with clumps of polar flagella.

**spirochete** A corkscrew-shaped bacterium with axial filaments.

**spontaneous generation** The idea that life could arise spontaneously from nonliving matter.

**spontaneous mutation** A mutation that occurs without a mutagen.

**sporadic disease** A disease that occurs occasionally in a population.

**sporangiophore** An aerial hypha supporting a sporangium.

**sporangiospore** An asexual fungal spore formed within a sporangium.

**sporangium** A sac containing one or more spores.

**spore** A reproductive structure formed by fungi and actinomycetes. *See also* endospore.

**sporogenesis** *See* sporulation.

**sporozoite** A trophozoite of *Plasmodium* found in mosquitoes, infective for humans.

**sporulation** The process of spore and endospore formation; also called sporogenesis.

**spread plate method** A plate count method in which inoculum is spread over the surface of a solid culture medium.

**staining** Colorizing a sample with a dye to view through a microscope or to visualize specific structures.

**staphylococci** (singular: **staphylococcus**) Cocci in a grapelike cluster or broad sheet.

**stationary phase** The period in a bacterial growth curve when the number of cells dividing equals the number dying.

**stem cell** An undifferentiated cell that gives rise to a variety of specialized cells.

**stereoisomers** Two molecules consisting of the same atoms, arranged in the same manner but differing in their relative positions; mirror images; also called D-isomer and L-isomer.

**sterile** Free of microorganisms.

**sterilization** The removal of all microorganisms, including endospores.

**steroid** A specific group of lipids, including cholesterol and hormones.

**stipe** A stemlike supporting structure of multicellular algae and basidiomycetes.

**storage vesicle** Organelles that form from the Golgi complex; contain proteins made in the rough ER and processed in the Golgi complex.

**strain** Genetically different cells within a clone. *See* serovar.

**streak plate method** A method of isolating a culture by spreading microorganisms over the surface of a solid culture medium.

**streptobacilli** (singular: **streptobacillus**) Rods that remain attached in chains after cell division.

**streptococci** (singular: **streptococcus**) (1) Cocci that remain attached in chains after cell division. (2) When written as a genus, refers to gram-positive, catalase-negative bacteria.

**streptokinase** A blood-clot dissolving enzyme, produced by beta-hemolytic streptococci.

**streptolysin** A hemolytic enzyme, produced by streptococci.

**structural gene** A gene that determines the amino acid sequence of a protein.

**subacute disease** A disease with symptoms that are intermediate between acute and chronic.

**subclinical infection** An infection that does not cause a noticeable illness; also called inapparent infection.

**subcutaneous mycosis** A fungal infection of tissue beneath the skin.

**substrate** Any compound with which an enzyme reacts.

**substrate-level phosphorylation** The synthesis of ATP by direct transfer of a high-energy phosphate group from an intermediate metabolic compound to ADP.

**subunit vaccine** A vaccine consisting of an antigenic fragment.

**sulfhydryl group** —SH.

**sulfur cycle** The various oxidation and reduction stages of sulfur in the environment, mostly due to the action of microorganisms.

**sulfur granule** See inclusion.

**superantigen** An antigen that activates many different T cells, thereby eliciting a large immune response.

**superbug** Bacterium resistant to a large number of antibiotics.

**superficial mycosis** A fungal infection localized in surface epidermal cells and along hair shafts.

**superinfection** The growth of a pathogen that has developed resistance to an antimicrobial drug being used; the growth of an opportunistic pathogen.

**superoxide dismutase (SOD)** An enzyme that destroys superoxide:  
 $O_2^- + O_2^- + 2 H^+ \rightarrow H_2O_2 + O_2$

**superoxide radical** A toxic anion ( $O_2^-$ ) with an unpaired electron.

**surface-active agent** Any compound that decreases the tension between molecules lying on the surface of a liquid; also called surfactant.

**susceptibility** The lack of resistance to a disease.

**symbiosis** The living together of two different organisms or populations.

**symptom** A change in body function that is felt by a patient as a result of a disease.

**syncytium** A multinucleated giant cell resulting from certain viral infections.

**syndrome** A specific group of signs or symptoms that accompany a disease.

**synergism** The principle whereby the effectiveness of two drugs used simultaneously is greater than that of either drug used alone.

**synthesis reaction** A chemical reaction in which two or more atoms combine to form a new, larger molecule.

**synthetic drug** A chemotherapeutic agent that is prepared from chemicals in a laboratory.

**systematics** The science organizing groups of organisms into a hierarchy.

**systemic anaphylaxis** A hypersensitivity reaction causing vasodilation and resulting in shock; also called anaphylactic shock.

**systemic (generalized) infection** An infection throughout the body.

**systemic mycosis** A fungal infection in deep tissues.

**tachyzoite** A rapidly growing trophozoite form of a protozoan.

**T antigen** An antigen in the nucleus of a tumor cell.

**tapeworm** A flatworm belonging to the class Cestoda.

**target cell** An infected body cell to which defensive cells of the immune system bind.

**taxa** Subdivisions used to classify organisms, e.g., domain, kingdom, phylum.

**taxis** Movement in response to an environmental stimulus.

**taxonomy** The science of the classification of organisms.

**T cell** A type of lymphocyte, which develops from a stem cell processed in the thymus gland, that is responsible for cell-mediated immunity. See also T cytotoxic cells, T helper cells, T regulatory cells.

**TCRs (T cell receptors)** Molecules on T cells that recognize antigens.

**T cytotoxic ( $T_C$ ) cells** A precursor to a cytotoxic T lymphocyte.

**T helper ( $T_H$ ) cell** A specialized T cell that often interacts with an antigen before B cells interact with the antigen.

**T regulatory ( $T_{reg}$ ) cells** Lymphocytes that appear to suppress other T cells.

**T-dependent antigen** An antigen that will stimulate the formation of antibodies only with the assistance of T helper cells. See also T-independent antigen.

**teichoic acid** A polysaccharide found in gram-positive cell walls.

**telomere** Noncoding regions of DNA at the ends of eukaryotic chromosomes.

**teleomorph** The sexual stage in the life cycle of a fungus; also refers to a fungus that produces both sexual and asexual spores.

**temperate phage** A phage capable of lysogeny.

**temperature abuse** Improper food storage at a temperature that allows bacteria to grow.

**terminator** The site on a DNA strand at which transcription ends.

**tertiary sewage treatment** A method of waste treatment that follows conventional secondary sewage treatment; nonbiodegradable pollutants and mineral nutrients are removed, usually by chemical or physical means.

**tetrad** A group of four cocci.

**thallus** The entire vegetative structure or body of a fungus, lichen, or alga.

**thermal death point (TDP)** The temperature required to kill all the bacteria in a liquid culture in 10 minutes.

**thermal death time (TDT)** The length of time required to kill all bacteria in a liquid culture at a given temperature.

**thermoduric** Heat resistant.

**thermophile** An organism whose optimum growth temperature is between 50°C and 60°C; a heat loving microbe.

**thermophilic anaerobic spoilage** Spoilage of canned foods due to the growth of thermophilic bacteria.

**thylakoid** A chlorophyll-containing membrane in a chloroplast. A bacterial thylakoid is also known as a chromatophore.

**thymus** A mammalian organ responsible for maturation of the immune system.

**thymic selection** Elimination of T cells that don't recognize self antigens (major histocompatibility complex).

**tincture** A solution in aqueous alcohol.

**T-independent antigen** An antigen that will stimulate the formation of antibodies without the assistance of T helper cells. See also T-dependent antigen.

**tinea** Fungal infection of hair, skin, or nails.

**Ti plasmid** A tumor-inducing plasmid that can be incorporated into a host plant chromosome; found in *Agrobacterium*.

**titer** An estimate of the amount of antibodies or viruses in a solution; determined by serial dilution and expressed as the reciprocal of the dilution.

**TLR (Toll-like receptor)** Transmembrane protein of immune cells that recognizes pathogens and activates an immune response directed against those pathogens.

**topoisomerase** Enzyme that relaxes supercoiling of DNA ahead of replication fork; separates DNA circles at the end of DNA replication.

**total magnification** The magnification of a microscopic specimen, determined by multiplying the ocular lens magnification by the objective lens magnification.

**toxemia** The presence of toxins in the blood.

**toxigenicity** The capacity of a microorganism to produce a toxin.

**toxin** Any poisonous substance produced by a microorganism.

**toxoid** An inactivated toxin.

**T plasmid** An *Agrobacterium* plasmid carrying genes for tumor induction in plants.

**trace element** A chemical element required in small amounts for growth.

**trans** Hydrogen atoms on opposite side across a double bond in a fatty acid. See *cis*.

**transamination** The transfer of an amino group from an amino acid to another organic acid.

**transcription** The process of synthesizing RNA from a DNA template.

**transduction** The transfer of DNA from one cell to another by a bacteriophage. See also generalized transduction; specialized transduction.

**transferrin** One of several human iron-binding proteins that reduce iron available to a pathogen.

**transfer RNA (tRNA)** The type of RNA molecule that brings amino acids to the ribosomal site where they are incorporated into proteins.



**transfer vesicle** Membrane-bound sacs that move proteins from the Golgi complex to specific areas in the cell.

**transformation** (1) The process in which genes are transferred from one bacterium to another as “naked” DNA in solution. (2) The changing of a normal cell into a cancerous cell.

**transient microbiota** The microorganisms that are present in an animal for a short time without causing a disease.

**translation** The use of mRNA as a template in the synthesis of protein.

**transmission electron microscope (TEM)** An electron microscope that provides high magnifications (10,000–100,000 $\times$ ) of thin sections of a specimen.

**transport media** Media used to keep microorganisms alive between sample collection and laboratory testing; usually used for clinical samples.

**transport vesicle** Membrane-bound sacs that move proteins from the rough ER to the Golgi complex.

**transporter protein** A carrier protein in the plasma membrane.

**transposon** A small piece of DNA that can move from one DNA molecule to another.

**trickling filter** A method of secondary sewage treatment in which sewage is sprayed out of rotating arms onto a bed of rocks or similar materials, exposing the sewage to highly aerobic conditions and microorganisms.

**triglyceride** A simple lipid consisting of glycerol and three fatty acids.

**triplex agent** A short segment of DNA that binds to a target area on a double strand of DNA blocking transcription.

**trophophase** The period in the production curve of an industrial cell population in which the primary metabolites are formed; a period of rapid, logarithmic growth. *See also* idiophase.

**trophozoite** The vegetative form of a protozoan.

**tuberculin skin test** A skin test used to detect the presence of antibodies to *Mycobacterium tuberculosis*.

**tumor necrosis factor (TNF)** A polypeptide released by phagocytes in response to bacterial endotoxins.

**tumor-specific transplantation antigen (TSTA)** A viral antigen on the surface of a transformed cell.

**turbidity** The cloudiness of a suspension.

**turnover number** The number of substrate molecules acted on per enzyme molecule per second.

**two-photon microscope** A light microscope that uses fluorescent stains and long wavelength light.

**ubiquinone** A low-molecular weight, nonprotein carrier in an electron transport chain; also called coenzyme Q.

**ultra-high-temperature (UHT) treatment** A method of treating food with high temperatures (140–150°C) for very short times to make the food sterile so that it can be stored at room temperature.

**uncoating** The separation of viral nucleic acid from its protein coat.

**undulating membrane** A highly modified flagellum on some protozoa.

**unsaturated** A fatty acid with one or more double bonds.

**use-dilution test** A method of determining the effectiveness of a disinfectant using serial dilutions.

**vaccination** The process of conferring immunity by administering a vaccine; also called immunization.

**vaccine** A preparation of killed, inactivated, or attenuated microorganisms or toxoids to induce artificially acquired active immunity.

**vacuole** An intracellular inclusion, in eukaryotic cells, surrounded by a plasma membrane; in prokaryotic cells, surrounded by a proteinaceous membrane.

**valence** The combining capacity of an atom or a molecule.

**vancomycin** An antibiotic that inhibits cell wall synthesis.

**variola** An early method of vaccination using infected material from a patient.

**vasodilation** Dilation or enlargement of blood vessels.

**VDRL test** A rapid screening test to detect the presence of antibodies against *Treponema pallidum*. (VDRL stands for Venereal Disease Research Laboratory.)

**vector** (1) A plasmid or virus used in genetic engineering to insert genes into a cell. (2) An arthropod that carries disease-causing organisms from one host to another.

**vegetative** Referring to cells involved with obtaining nutrients, as opposed to reproduction.

**vehicle transmission** The transmission of a pathogen by an inanimate reservoir.

**vertical gene transfer** Transfer of genes from an organism or cell to its offspring.

**vesicle** (1) A small serum-filled elevation of the skin. (2) Smooth oval bodies formed in plant roots by mycorrhizae.

**V factor**  $\text{NAD}^+$  or  $\text{NADP}^+$ .

**vibrio** (1) A curved or comma-shaped bacterium. (2) When written as a genus (*Vibrio*), a gram-negative, motile, facultatively anaerobic curved rod.

**viral hemagglutination** The ability of certain viruses to cause the clumping of red blood cells in vitro.

**viral hemagglutination inhibition test** A neutralization test in which antibodies against particular viruses prevent the viruses from clumping red blood cells in vitro.

**viral species** A group of viruses sharing the same genetic information and ecological niche.

**viremia** The presence of viruses in the blood.

**virion** A complete, fully developed viral particle.

**viroid** Infectious RNA.

**virology** The scientific study of viruses.

**virulence** The degree of pathogenicity of a microorganism.

**virus** A submicroscopic, parasitic, filterable agent consisting of a nucleic acid surrounded by a protein coat.

**volutin** Stored inorganic phosphate in a prokaryotic cell. *See also* metachromatic granule.

**Western blotting** A technique that uses antibodies to detect the presence of specific proteins separated by electrophoresis.

**whey** The fluid portion of milk that separates from curd.

**xenobiotics** Synthetic chemicals that are not readily degraded by microorganisms.

**xenodiagnosis** A method of diagnosis based on exposing a parasite-free normal host to the parasite and then examining the host for parasites.

**xenotransplantation product** A tissue graft from another species; also called xenograft.

**X factor** Substances from the heme fraction of blood hemoglobin.

**yeast** Nonfilamentous, unicellular fungi.

**yeast infection** Disease caused by growth of certain yeasts in a susceptible host.

**zone of inhibition** The area of no bacterial growth around an antimicrobial agent in the disk-diffusion method.

**zoonosis** A disease that occurs primarily in wild and domestic animals but can be transmitted to humans.

**zoospore** An asexual algal spore; has two flagella.

**zygospore** A sexual fungal spore characteristic of the zygomycetes.

**zygote** A diploid cell produced by the fusion of two haploid gametes.



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# INDEX

Note: a *t* following a page number indicates tabular material, an *f* following a page number indicates a figure or illustration, a *b* indicates a boxed feature, and a page number in **boldface** indicates a definition.

## A

A-B toxins, **438–439**, 438*f*, 441*t*, 442*t*  
 ABLV (*Australian bat lyssavirus*), 630  
 ABO blood group system, **532–533**, 532*t*  
   IgM antibody and, 483, 526  
   transfusions and, 532–533  
 abortions  
   gas gangrene and, 646  
   spontaneous, *Campylobacter fetus* and, 313  
 abscess, **465**, **593**  
   in inflammatory response, 464*f*, 465  
 absorbance (optical density/OD), 175, 176*f*  
 absorption processes in digestion, 712  
*Acanthamoeba*, 351, 356*t*, 635  
*Acanthamoeba* keratitis, **605**  
 accelerators (chemical), allergic reactions and, 531  
 accessory glands, of male reproductive system, 745, 745*f*  
 accidental inoculation, 406  
 Accutane (isotretinoin), 455, 600  
 acetaldehyde, 133, 133*f*  
 acetaminophen, 440  
 acetate kinase, 115*t*  
 acetic acid  
   *acetobacter* and, 134*t*, 300*t*, 304  
   bacteria that produce, 300*t*  
   fermentation and, 132*f*, 134*t*  
   industrial/commercial use, 134*t*  
*Acetobacter* genus/spp., 134*t*, 137, 300*t*, **304**, 806  
*Acetobacter xylinum*, 263  
 acetoin, 132*f*, 282*b*, 284*f*, 285*f*, 286  
 acetone, 2  
   biotechnology and, 244  
   fermentation and, 132*f*, 134*t*  
 acetyl CoA (acetyl coenzyme A), 122, 123*f*, 125  
   in amino acids biosynthesis, 144–145, 145*f*  
   Krebs cycle and, 125–127, 126*f*  
   in lipid biosynthesis, 144, 145*f*  
   in lipid catabolism, 136*f*  
   in nucleotide biosynthesis, 145–146, 146*f*  
 acetyl-CoA synthetase, 115*t*  
 acetyl group, 125, 127  
 acetylcholine, rabies virus can mimic, 443  
 acid-anionic surface sanitizers, **196**, 202*t*  
 acid-base balance, 34–36, 35*f*  
 acid-fast bacteria, 69, 70*f*, 71*t*, 87–88

acid-fast stain, **69**, 70*f*, 71*t*, 284  
   mycolic acid and, 88  
 acid fuchsin dye, 67  
 acid precipitation, lichens and, 342  
 acid-tolerant microbes, 35, 326  
 acidic dyes, 67  
 acidic solutions, 34*f*, 35, 35*f*  
   alkaline vs., 35, 35*f*  
   microbial growth and, 35, 156  
 acidophiles, **156**  
 acidophilic archaea, 326  
 acidophilic inclusion bodies, 443, 445*t*  
 acidosis, fever and, 466  
 acids vs. bases, **34–36**, 34*f*, 35*f*  
*Acinetobacter baumannii*  
   antibiotic resistance and, 309, 571  
   as superbug, 580  
*Acinetobacter* genus/spp., **309**  
   genetic transformation naturally occurring in, 233  
   as normal microbiota of skin, 404*t*, 591  
   nosocomial infections and, 416*t*  
 acne, 455, **597*b***, **599–600**, 600*f*  
   bacterial, 319, 597*b*  
   clindamycin to treat, 570  
 acoustic microscopy, scanning (SAM), **61**, 62*f*, 66*t*  
 acquired immunity. *See also* adaptive immunity  
   active vs. passive, 494–495, 494*f*  
   natural vs. artificial, 494–495, 494*f*  
 acquired immunodeficiencies, **544**, 544*t*  
 acquired immunodeficiency syndrome (AIDS). *See* AIDS  
 acridine dyes, 227  
 Actimmune (beta interferon), to treat osteoporosis, 473  
 actin  
   *Listeria* uses to self-propel, 435  
   rearranged by invasions, 435  
 Actinobacteria, 302*t*, **318–320**, 319*f*, 320*f*  
   as high G + C gram-positive bacteria, 280*f*, 302*t*, 318  
*Actinomyces* genus/spp., 301*t*, 302*t*, **320**, 320*f*  
   actinomycetes informal name for, 318–319  
   fimbriae of, adherence and, 432  
   as normal microbiota of mouth, throat, 320, 404*t*  
   *Streptococcus mutans*, dextran, and dental plaque, 432, 441, 713  
*Actinomyces israelii*, actinomycosis caused by, 320  
 Actinomycetales, 302*t*  
 actinomycetes, 318–319  
   antibiotics produced by, 550*t*  
   estimating number of, 177  
   G + C ratio of, 314  
   morphology of, 320  
   reproductive methods, 168  
 actinomycosis, 320  
 activated macrophages, **495**, 495*f*, 496*t*  
 activated sludge system, **790–791**, 791*f*  
 activation energy, **113**, 114*f*  
 activation of complement system, **488**, 488*f*  
 active immunity, **498**, 498*f*  
   artificially acquired, **495**, 498*f*  
   naturally acquired, **498**, 498*f*  
 active site of enzymes, 113, **115**, 116*f*, 118*f*  
 active transport processes, 91, **93**, 144  
 ACTs (artemisinin-based combination therapies), 577, 671  
 acute bacterial endocarditis, **648**, **649*b***  
 acute disease, **409**  
 acute hepatitis B, **730**  
 acute inflammation, 463  
 acute necrotizing ulcerative gingivitis (trench mouth), **716**, 716*f*  
 acute-phase proteins, **463**  
 acyclovir, 562*t*, 566*t*, **575**, 576*f*  
   to treat herpes encephalitis, 603  
   to treat shingles, 602  
 ADA (adenosine deaminase)  
   deficiency, 16  
 adapalene (Differin), 599  
 adaptive immunity, 435, **452**, 452*f*, **478–503**  
   active  
     artificially acquired, **498**, 498*f*  
     naturally acquired, **498**, 498*f*  
   antigens, **481**, 481*f*  
   blood's role in, 643, 644, 645*f*  
   cellular, **480**, 485–487  
   dual nature of, 479–480, 500*f*  
   humoral, 479–**480**, 500*f*  
     B cells in, 482–486  
   lymph's role in, 644–645, 645*f*  
   memory component of, 452, 479, 497, 497*f*  
   nonspecific vs. self and, 477, 497, 500*f*  
   passive  
     artificially acquired, **498**, 498*f*  
     naturally acquired, **498**, 498*f*  
   specificity of, 452  
   summary, 500*f*  
   as third line of defense, 452, 452*f*  
   types of, 497–499, 498*f*  
 ADCC. *See* antibody-dependent cell-mediated cytotoxicity  
 Addison's disease, 539*t*  
 adefovir dipivoxil (Hepsera), 566*t*  
   to treat hepatitis B, 575  
 adenine (A), 46*f*, 47, 48*f*, 208  
   in DNA replication, 210–215, 211*f*–214*f*  
   exposed to mutagenic nitrous acid, 226, 226*f*  
   in translation, 215*f*, 216, 216–217*f*  
 adenine nucleotide, 46*f*, 47  
 adenocarcinomas (virus-induced), **392**  
 adenosine, 47, 48*f*

adenosine deaminase (ADA)  
   deficiency, 16  
 adenosine diphosphate (ADP), **47–48**, 48*f*  
   anabolic reactions and, 112, 112*f*  
 adenosine diphosphoglucose (ADPG), 144, 144*f*  
 adenosine monophosphate/AMP, 46*f*, 47  
 adenosine triphosphate (ATP), 47. *See also* ATP  
 Adenoviridae, **377*t***, **386**  
   *Mastadenovirus*, 372*f*, 388*f*  
   as an oncogenic DNA virus, 393  
 adenoviruses, 372*f*, 373, **386**, 388*f*  
   conjunctivitis and, 609  
   cytopathic effects of, 445*t*  
   as opportunistic pathogens, 405  
   size of, 372*f*  
   used in gene therapy, 249, 258  
 adherence (pathogenic), **432–433**, 432*f*, **447*f***, **460–462**, 461*f*  
 adhesins (ligands), **432–433**, 432*f*  
   virulence factors and, 441–442  
 adjuvants to antigens, **506**  
 ADP (adenosine diphosphate), **47–48**, 48*f*  
   in Calvin-Benson cycle, 140*f*  
   in generation of ATP, 120–121  
   in photosynthesis, 138, 139*f*  
 ADPG (adenosine diphosphoglucose), 144, 144*f*  
 adsorption (attachment) stage in viral multiplication, **381**, 382*f*, **385**, 385*t*, 387*f*  
 adult stem cells (ASCs), 540  
*Aedes aegypti* (mosquito), 413*t*, 675*b*  
*Aedes albopictus* (mosquito), 668  
*Aedes* (mosquito), 364*t*  
   California encephalitis transmitted by, 628*b*  
   chikungunya fever transmitted by, 658  
   dengue fever/yellow fever/heartworm transmitted by, 364*t*, 413*t*, 658  
   eastern equine encephalitis transmitted by, 628*b*  
   heartworm disease and, 362  
 aerial hyphae, 333, 333*f*, 336*f*  
 aerobes, **125**  
   culture media and, 161–166  
   fungi as, 332  
   obligate, **159**, 159*t*  
   vs. anaerobes, **125**, 130  
 aerobic respiration, **125–130**  
   anaerobic respiration vs., 135*t*  
   ATP yields and, 130, 130*t*, 135*t*  
   chemiosmosis and, 128–130, 129*f*  
   effect of oxygen on bacterial growth, 159, 159*t*  
   electron transport chain and, 127–130, 127*f*, 129*f*

- fermentation vs., 135t  
final electron acceptor in, 135t, 141f  
growth conditions and, 135t  
Krebs cycle, 125–127, 126f  
phosphorylation used to generate ATP, 135t  
summary, 129–130, 131f  
*Aeromonas hydrophilia*, 282b  
aerotolerant anaerobes, 159t, 160  
affinity, in antigen-antibody complex, 487  
aflatoxin, 445, 735  
as frameshift mutagen, 227  
poisoning, 735, 740b  
produced by *Aspergillus flavus* mold, 227, 445, 735  
AFM (atomic force microscope), 58f, 64, 64f, 67t  
African sleeping sickness (trypanosomiasis), 219, 330, 350, 356t, 364t, 413t, 414t, 435, 446, 633, 638b  
agar, 162  
algae-derived, 346  
bismuth sulfite, 165  
blood, 165, 165f  
MacConkey's, 746, 748f  
mannitol salt, 165, 166f  
nutrient, 163  
peptone iron, 137f  
properties of, 162  
Sabouraud's dextrose, 165  
salt concentration and, 158  
temperature and, 162  
agarose gel, 261, 262f  
Agent Orange, decomposition rate, 775, 775f  
agglutination, 487, 488f, 515  
epitopes of antigens and, 481, 481f  
IgG antibodies and, 483t, 484–485  
IgM antibody and, 480  
slide agglutination test, 286, 286f  
agglutination reactions, 515–517, 515f, 516f  
direct, 515–516, 516f  
hemagglutination, 517, 517f  
indirect (passive), 516–517, 516f  
latex, 511–512, 511f  
aging  
immune system's gradual decline and, 465  
phagocyte's progressive inefficiency and, 465  
agranulocytes, 456, 457t  
dendritic cells, 456, 457t  
lymphocytes, 457t, 458  
monocytes, 456, 457t  
agranulocytosis, 534  
Agre, Peter, 13t  
agriculture. *See also* soil  
antibiotic overuse/misuse and, 237  
bacteria important to, 304–305  
DNA technology applications in, 263–264, 264f, 266, 267t  
fungi's beneficial and undesirable effects for, 339  
microbial insect control, 16, 263–264, 266, 267t  
wastes of, fermentation and, 134t  
*Agrobacterium* genus/spp., 300t, 304–305  
Entner-Doudoroff pathway and, 125  
as rDNA vehicle, 237, 263–264, 264f, 305  
*Agrobacterium tumefaciens*, 305  
crown gall disease and, 263, 264f, 305  
Ti plasmid rDNA technology and, 263–264, 264f, 305  
AIDS, 5f, 20, 544t, 545–554. *See also* HIV; HIV infection  
as a pandemic disease, 409  
CD4+ T cells and, 5f, 443, 544t, 545–550, 546f, 548f  
chemotherapy for, 548  
chimpanzee, 379  
clinical definition of, 549  
deaths from, worldwide, 551, 552f  
diagnostic methods, 550–551  
diseases commonly associated with, 550t  
distribution of cases, worldwide, 551, 552t  
earliest documented case of, 545  
ELISA test to detect HIV antibodies, 286, 287f, 521, 523f, 550  
as emerging infectious disease, 419t  
as an epidemic disease, 408, 408f, 546, 547f, 548  
feline, 379  
as final stage of HIV infection, 549  
gene therapy research and, 549  
genetics and, 549  
in health care settings, compromised hosts and, 416  
historical aspects, 545  
importance of basic scientific research in, 554  
incubation period, 431t  
microsporidia infections and, 337  
opportunistic infections and, 405  
fungal infections, 340–341, 340t  
origins of, 545  
persistent viral infections and, 396t  
*Pneumocystis pneumonia* as leading cause of death, 330  
portals of entry, 431t  
prevention of, 551–553  
progression from initial HIV infection to, 547–549, 548f  
reported cases in United States 1979–2006, 408f  
as sexually transmitted infection, 765  
simian, 379  
toxoplasmosis of brain and, 549, 550t, 662–663  
transmission routes, 447, 551  
treatment regimens for, 553, 571  
vaccine development and, 379, 509, 547, 552–553  
air, spontaneous generation theory, microbes and, 8–9, 11  
air conditioning systems, *Legionella* and, 309  
air pollutants, lichens used to determine, 342  
airborne microorganisms  
chlamydia and, 322  
*Coxiella burnetii* and, 309  
early theories of, 7, 8–9, 9f, 11  
in health care facilities, 416, 417  
HEPA filters and, 164, 188  
pathogenic, systemic mycoses and, 339  
transmission of disease and, 412, 412f, 417  
UV light to control, 190  
*Ajellomyces (Blastomyces) dermatitidis*, 340t  
*Ajellomyces (Histoplasma) capsulatum*, 340t  
alanine (Ala), structural formula/characteristic R group, 42t  
alanine deaminase, 115t  
alanine racemase, 115t  
alarm signals (chemical)  
alarmones, 221–222  
cyclic AMP as, 221–222, 223f  
alarmones, 221–222  
cyclic AMP as, 221–222, 223f  
albendazole, 566t, 577  
alcohol  
enzymes in peroxisomes and, 104  
in Gram staining, 68, 68f, 86  
alcohol fermentation, 133, 133f, 806  
alcohol functional group, 36t, 37  
alcoholic beverages  
fermentation and, 8, 134b, 134t, 806  
microbes used in production of, 800  
alcohols, 36t, 37  
as disinfectants, 194–195, 194t, 201t, 202t  
plasma membrane damaged by, 90, 194  
aldehyde functional group, 36t  
aldehydes, 197, 202t  
alder trees, *Frankia* and, 319  
ale, microbes used in production of, 806  
alemtuzumab, 514  
allergic reactions, as type of immune response, 484–485  
*Alexandrium*, 346, 356t  
neurotoxin (saxitoxin) produced by, 446  
red tide and, 346  
alexidine, 193  
alfalfa plants, symbiotic relationships with microbes and, 266  
algae, of swimming pool walls, biofilms and, 432  
algae/alga, 2, 5, 5f, 330, 331f, 343–348  
as a biofuel, 808, 808f  
agar derived from, 162, 346  
brown, 345–346, 345t  
as carbon dioxide recyclers, 15  
cell structure, 5, 5f, 98f, 99  
cellulose and, 38, 99  
characteristics of, 5, 343–345, 344f, 345f, 345t  
chemoheterotrophic, 342  
chloroplasts of, 103–104, 105f, 138  
classification and, 342  
copper sulfate as algicide, 199, 202t  
cyanobacteria once called, 320  
death of, 344  
diatoms, 341f, 343, 343f, 345t  
dinoflagellates (plankton), 345t, 346–347, 346f  
Earth's molecular oxygen produced by, 345  
as eukaryotes, 75, 341  
filamentous, 341, 341f  
fungal-like (oomycetes/water molds), 345t, 347–348, 347f  
genetic engineering and, 251, 252f  
green, 345f, 345t, 346  
habitats of, 343, 344f  
human diseases caused by, intoxications and, 331f  
identification of, 341  
inserting foreign DNA into cells of, 251  
kelp (brown algae), 341, 341f, 342, 345t  
in lichens, 342  
life cycle of, 344, 345f  
morphology of, 341  
multicellular, 341–342, 341f, 342f  
neurotoxins produced by, 446  
nutritional requirements, 5, 344, 345t  
pathogenic, 345t, 446  
as photoautotrophs, 141–143, 141f, 341  
photosynthesis and, 138, 143t, 341f, 342, 345t  
plankton (dinoflagellates), 345t, 346–347, 346f  
pond, 5f  
protoplast fusion to genetically manipulate, 251, 252f  
red, 341f, 345t, 346  
reproductive methods, 5  
role in nature, 344–345  
rules for naming, 278  
thalli of, 341–342, 341f, 343f  
toxins produced by, 331f  
unicellular, 341, 341f  
vegetative structures, 341–342  
*Volvox*, 5f  
water molds, 344, 345f, 345t  
algal blooms, 348, 785, 785f  
algin, 345–346  
alginic acid, 345t  
*Aliivibrio fischeri*, producing enzyme luciferase, 56b  
alimentary canal, 712. *See also* gastrointestinal (GI) tract  
alkaline habitats, cyanobacteria and, 35  
alkaline solutions, 34f, 35, 35f  
acidic vs., 35, 35f  
microbial growth and, 156  
alkalinity, microbial growth and, 156  
alkylation, 198  
All Species Inventory project, 273  
allergen, 528  
allergic contact dermatitis, 528t, 535, 536f, 537b  
allergic reactions, 528–531. *See also* hypersensitivity  
IgE antibodies and, 481, 523, 524f  
to penicillin, 481, 530  
allergy, 528–531, 528t. *See also* hypersensitivity  
allografts, 541  
allosaccharose, 219, 221f  
allosteric enzyme inhibitors, 118, 118f  
feedback (end-product) inhibition and, 118, 118f  
allosteric inhibition, 118, 118f  
allosteric site, 118, 118f

- allylamine antifungal antibiotics, 566t, 574
- alpha-amino acids, 41, 41f
- alpha-carbon, 41
- alpha-glucosidase, 259t
- alpha-hemolytic streptococci, 317
- alpha interferon, 259t, 471–473, 471f, 566t
- as an antiviral drug, 566t
- to treat viral hepatitis, 575
- alpha-ketoglutaric acid, 126f, 145f, 147f
- alphaproteobacteria, 299, 300t, 303–306, 304f, 305f
- important genera/special features, 300t
- Alphavirus*, 413t
- causing dengue fever, 413t
- alphaviruses, 377t, 388
- alternative pathway of complement activation, 467, 468f, 470f
- alum, as adjuvant to antigen effectiveness, 506
- alveolar macrophages, 460, 681
- alveoli, 681, 682f
- Alzheimer disease, complement proteins implicated in, 470
- Amanita phalloides* (deathcap mushroom), 445
- amanitin, 445
- amantadine, 566t
- Amebae, 4, 5f, 350–351, 351f, 356t
- position in evolutionary tree, 274f
- quats effective against, 196
- slime molds and, 4, 353–354, 354f, 355f
- amebiasis. *See* amebic dysentery
- amebic dysentery (amebiasis), 330, 351, 351f, 356t, 738, 738f, 740b
- diiodohydroxyquin (iodoquinol) to treat, 571, 738
- metronidazole to treat, 571, 738
- portal of entry, 430
- portal of exit, 446
- amebic encephalitis, granulomatous, 623b
- amebic meningoencephalitis, primary, 623b, 634–635, 635f
- American Academy of Microbiology, 263
- American leishmaniasis, 666
- American trypanosomiasis. *See* Chagas' disease
- Ames test, 230–231, 230f, 232b
- amination, 145, 145f
- amines, aromatic, formed in high-heat cooking, 231b, 232b
- amino acids, 41–44, 41f, 42t
- amphibolic pathways and, 146, 147f
- biochemical tests and, 136–137, 137f
- biosynthesis of, 144–145, 145f
- D-amino acid configuration, 41, 80
- found in proteins, 42t
- metabolism, coenzyme in, 115t
- mutation and their effects on, 223–224, 225f
- peptide bonds of, 43, 44f
- porins and, 86
- in protein biosynthesis, 144–145, 145f
- in protein catabolism, 136f
- protein structure and, 43–44, 45f
- structure of, 41, 41f, 42f
- in translation (protein synthesis), 215–218, 216–217f, 218f
- amino functional group, 36t, 37, 41, 41f, 42t, 43
- in deamination conversion, 136
- para*-aminobenzoic acid (PABA), 118, 573
- aminoglycosides, 565t, 570
- ammonia
- in chloramines, 194
- as an energy source, 139, 141f, 143
- ammonification, 776–777, 776f
- ammonium ion, 135
- in quats, 196, 196f
- Amoeba proteus*, 351f
- amoxicillin, 564t, 568
- AMP/adenosine monophosphate (adenine nucleotide), 46f, 47
- amphibolic pathways, 146, 147f
- amphitrichous flagella, 80f, 81
- amphotericin B, 342b, 566t, 574, 574f, 639b
- produced by *Streptomyces nodosus*, 560t
- ampicillin, 564t, 567f, 568
- ampicillin resistance gene (*amp<sup>R</sup>*), 249, 249f, 255, 255f
- amplified DNA, 245, 249–251, 250f, 290
- Ampligen, 633
- amp<sup>R</sup>* (ampicillin-resistance gene), 249, 249f, 255, 255f
- AMPs. *See* antimicrobial peptides
- amylases, 38, 246f
- Anabaena azollae*, 776f
- Anabaena* genus/spp., 302t, 321t
- anabolic chemical reactions. *See* anabolism
- anabolism, 32, 112, 112f, 144–147, 144f–147f
- amphibolic pathways and, 146, 147f
- anaerobes
- aerotolerant, 159t, 160
- facultative, 159, 159t
- growth media for, 163, 164f
- vs. aerobes, 130, 159
- anaerobic chambers, 163, 164f
- anaerobic respiration, 125, 130, 159
- aerobic respiration vs., 125, 135t
- ATP yields and, 135t
- fermentation vs., 135t
- final electron acceptor in, 135t, 141f
- growth conditions and, 135t
- phosphorylation used to generate ATP, 135t
- anaerobic sludge digesters, 792–793, 797f
- anal gonorrhea, 756
- anal pore, 349, 353f
- analytical epidemiology, 421
- anamnestic response, memory (secondary response), 497, 497f
- anamorphs, 338, 340t
- anaphylactic reactions, 528–531, 528t, 529f
- IgE antibodies and, 481, 528–531, 528t, 529f
- inherited complement deficiencies and, 470
- localized, 528, 530–531, 530f
- preventing, 531
- skin tests to identify antigens, 531, 531f
- systemic, 528, 529–530
- as Type I hypersensitivity, 528t
- anaphylactic shock (systemic anaphylaxis), 528, 529–530
- anaphylaxis, 528, 529f
- localized, 530–531, 530f
- systemic, 528, 529–530, 529f
- Anaplasma*, as obligately intracellular human pathogen, 300t
- Anaplasma phagocytophilum*, 654
- anaplasmosis caused by, 654
- Ixodes scapularis* as tick vector, 654
- anaplasmosis, 290, 656b
- as notifiable infectious disease, 424t
- ancestors, universal, 274f, 275, 275f, 277
- ancestral relationships, classification systems and, 273, 274f
- Ancylostoma duodenale*, 361, 364t, 740b, 741, 741f
- anemia
- Babesia microti* causing, 352
- genetically modified erythropoietin to treat, 259t
- hemolytic, 534
- human parvovirus B19, 377t
- anesthesia, compromised hosts and, 416
- Angstrom (Å), 55
- animal bite infections
- bat, 628–630, 630footnote, 631b, 631f, 667b
- cat, 312, 653–654, 655b
- dog, 312, 630f, 653, 655b
- rat, 654–655, 655b. *See also* rodents
- animal dander, allergic reactions to, 525
- animal feed antibiotics, 559, 562t, 565, 575, 583b
- avoparcin, 583b
- fluoroquinolones, 583b
- human disease linked to, and safety of, 575, 583b
- livestock, 554, 562t, 565, 575, 583b
- tetracyclines, 562t, 565
- vancomycin, 583b
- animal hides, *B. anthracis* infections and, 43b, 44b, 48b
- animal husbandry
- animal feed antibiotics and, 559, 562t, 565, 575, 583b
- bovine growth hormone (bGH) and, 266, 267t
- porcine growth hormone (pGH), 267t
- rDNA products important to, 266, 267t
- animal reservoirs, 411, 413t
- animal viruses
- cultivation of, 379–380, 379f, 380f, 406, 504
- in embryonated eggs, 379, 379f, 406, 504
- genetic modification of, 257
- multiplication of, 385–392, 385t, 388t
- biosynthesis and
- of DNA viruses, 385–388, 385t, 387f, 388t
- of RNA viruses, 385t, 388–391, 388t, 389f
- entry methods, 385, 386f
- stages in, 385–386, 385f
- uncoating and, 385–386
- vs. in bacteriophages, 385
- “animalcules”, 6, 7f
- Animalia (kingdom)
- energy source, 281
- in Linnaeus's classification system, 273
- organisms included in, 281
- animals
- cell structure (eukaryotic), 75, 97–106, 98f
- cells used to produce viral vaccines, 245
- as chemoheterotrophs, 141, 141f, 143
- DNA vaccines approved for, 503
- intestinal tract bacteria of, 310
- as kingdom in Domain Eukarya, 6, 274f
- microinjecting foreign DNA into, 252, 253f
- mud-dwelling, 14
- nutritional classification of, 141, 141f
- parasites of, 5–6. *See also* parasites
- position in evolutionary tree, 274f
- as reservoirs, 411, 413t
- spontaneous abortion, *Campylobacter fetus* and, 313
- transgenic, 258, 259t, 267t
- wild, veterinary microbiologists and, 282b
- animicrobial agents, usnic acid from *Usnea* lichen, 342
- anionic detergents, 88t
- gram-negative vs. gram-positive bacteria and, 88t
- anions, 30, 34
- superoxide, 159–160
- anisakiasis (sashimi worms), 364t
- anisakines*, 362, 364t
- Anopheles* (mosquito), as malaria vector, 351–352, 352f, 356t, 362–363, 364t, 413t, 414t, 663
- anoxygenic photosynthetic bacteria, 95, 141f, 142, 143t, 302t, 321t, 323–326, 325f
- antagonism
- in combination antibiotics, 584
- microbial, normal microbiota and, 403–405
- antheridial hyphae, 345f
- anthrax, 441t, 650–652, 651f, 655b
- as a biological weapon, 315, 652, 654b
- causative agent discovered, 11, 406, 650
- caused by *Bacillus anthracis*, 11, 80, 235, 315, 406, 413t, 419t, 431, 432, 441t
- chlorine dioxide gas to fumigate, 198
- Cipro (ciprofloxacin) to treat, 572, 646
- cutaneous, 432, 651, 651f, 655b
- disease reservoirs for, 413t



- DNA fingerprinting, biologic weapons and, 261
- as emerging infectious disease, 419*t*
- endospores of, 95–97, 96*f*, 650
- gastrointestinal, 432, **651**–652, 655*b*
- inhalational (pulmonary), 432, **652**, 654*b*, 655*b*
- as notifiable infectious disease, 424*t*
- portals of entry and, 431, 432, 650–652
- stain used to diagnose, 59
- transmission due to, 413*t*
- vaccination of livestock and, 652
- vaccine for humans, 652
- virulence of, 80, 432, 433, 650–652
- as zoonotic disease, 413*t*
- antibiograms, **579**
- antibiosis, laboratory observation of, 559, 559*f*
- antibiotic resistance, 12, 18, 19, 20, **558**, 579–584
- Acinetobacter baumannii* and, 309
- animal feed antibiotics and, 559, 562*t*, 565, 582, 583*b*
- bacterial mutations and horizontal gene transfer, 581, 582*f*, 583*b*
- biofilms and, 17, 161
- cost of, 582
- development of during antibiotic therapy, 581, 582*f*
- to disinfectant triclosan, 192–193, 201*f*
- future solutions proposed, 584–585
- as global health crisis, 18, 581, 582*f*
- gonorrheal therapies and, 756*b*
- health care-associated infections and, 415, 581
- infectious disease reemergence and, 20
- mechanisms of, 579–581, 580*f*
- cell wall porins and, 309
- misuse of antibiotics and, 18, 19, 415, **581**–582, 582*f*, 583*b*
- MRSA and, 18, **560**–561. *See also* MRSA
- mutation and, 207, 231, 580–581, 582*f*
- of *neisseria gonorrhoeae*, 751*b*
- new approaches to solving, 584–585
- nosocomial infections and, 415, 581
- plasmid vector used for cloning, 249, 249*f*
- plasmids and, 95, 441–442, 574. *See also* plasmids
- pneumococcal diseases and, 614
- prevention of, 582
- of pseudomonads, 594
- R factors in bacteria and, **235**–237, 238*f*, 308, 308*f*, 414, 441–442, 574, 583*b*
- resistant mutants and, 581, 582*f*
- sex pili, enterics and, 310
- superbugs and, **580**
- transferred between different genera and, 235–237, 580
- transposons and, 580
- antibiotics, **11**–12, 69, **559**. *See also* antimicrobial drugs
- in animal feeds, 559, 562*t*, 565, 582, 583*b*
- antagonism in combinations, **584**
- antibacterial, 564–565*t*, 567–573
- antibiosis and, 559, 559*f*
- antifungal, 566*t*, **573**–575
- antihelminthic, 566*t*, **577**
- antimycobacterial, 564*t*, **569**
- antiprotozoan, 12, 528, 529*f*, 566*t*, **577**
- antiviral, 566*t*, 575–577
- bacterial mutants developed during therapy, 581, 582*f*
- blood-brain barrier and, 611
- broad-spectrum, **560**, 562*t*
- normal microbiota altered by, 403–405, 555, 561–562
- opportunistic fungal infections and, 340–341
- superinfections and, 561
- combination drugs, synergism and, 571, 573*f*, 584, 584*f*
- commonly used
- against fungi/viruses/protozoans/helminths, **566*t***
- arranged by mode of action, **564**–565*t*
- derived from microbes, 245, 247, 302*t*, 317, 320, 341, 559, 560*t*, 563
- diarrhea associated with, **441*t***
- discovery of, 12, 12*f*, 244, 558, 559, 560
- endotoxins and, 440
- enzymatic inactivation of, 580–581, 580*f*
- future of, 584–585
- gram-negative bacteria and, 88, 562*t*
- gram-positive bacteria and, 70, 562*t*
- intestinal microbiota altered by, 314, 403–405, 555, 561–562
- microbial susceptibility tests, 572–573, 572*f*, 573*f*
- misuse/overuse, 18, 19, 237, 415, **581**–582, 582*f*, 583*b*
- as factor in emerging infectious diseases, 418
- modes of action of commonly used, 561*f*, 564–565*t*
- narrow-spectrum, **560**–561, 562*t*
- normal microbiota and, 403–405, 555, 561–562
- rashes induced by, 537*b*
- resistance to, 12, 18–19. *See also* antibiotic resistance
- nosocomial infections and, 422*b*
- with ribosomal activity, 94, 101, 563, 565–566
- safety issues, 583*b*, 584
- sensitivity tests, 572–573, 572*f*, 573*f*
- sterilization of (by filtration), 188
- Streptomyces* species produces many, 320, 560, 560*t*
- superinfections and, **555**
- susceptibility testing, 195, 196*f*, 577–579, 751*b*
- susceptibility to (Archaea/Bacteria/Eukarya compared), 276*t*
- synergism in combinations of, 571, 573*f*, **583**, 583*f*
- therapeutic index and, 584
- for use in foods as antimicrobials, 197
- viral insensitivity to, 370*t*
- antibodies (immunoglobulins), **59**, 61*f*, 286, 480, **481**–485, 482*f*, 483*t*
- antibody titer, **497**, **510**, 511*f*
- antigen-binding sites, **482**, **487**–488, 488*f*
- antigenic variation and, 435
- antisera and, 286
- antitoxins (against exotoxins) produced by, 438
- in artificially acquired passive immunity, 494*f*, 495
- B cells (B lymphocytes) and, 485, 486*f*
- blood's role in, 637–638, 639*f*
- classes of, 483–485, **483*t***. *See also* immunoglobulins
- cytotoxicity and, 487, **488**, 488*f*, 495, 500*f*
- diversity of, 487
- early discoveries about, 479
- endotoxins and, 441, 442*t*
- first ones produced in infection, 483*t*, 497, 497*f*
- fully human antibodies, **514**
- as globulin proteins, 41, 479
- half-life of an injected antibody, 495
- humanized, **514**
- humoral immunity and, **480**. *See also* humoral immunity
- IgA proteases enzymes and, 435
- intracellular antigens and, 486
- monoclonal, 259*t*, **512**–514, 513*f*
- neutralization and, 487, **488**, 488*f*
- opsonization and, 487, **488**, 488*f*
- placental transfer of, 494–495
- primary response to an antigen, **493**
- serological testing and, 286–287, 286*f*, 287*f*, 288*f*
- specificity of, **484**
- structure of, 482, 482*f*, 483*t*
- T-dependent antigens and, **482**, 482*f*
- as third line of defense, 452*f*
- viruses and, 373, 379
- antibody-dependent cell-mediated cytotoxicity (ADCC), 487, **488**, 488*f*, **495**, 496*f*, 529
- antibody titer, **497**, **510**, 511*f*
- anticancer drugs
- nucleoside analogs and, 226–227, 227*f*
- taxol produced by *Taxomyces* fungus, 341
- anticodon, 216*f*, **217**
- antifungal drugs, 445, **566*t***, **573**–575, 574*f*
- antigen, tumor-specific transplantation (TSTA), **393**
- antigen-antibody complex, 467, **487**–489, 488*f*
- antigen-antibody reactions
- complement activation classical pathway and, 467, 468*f*, 469*f*
- fluorescent-antibody (FA) technique to identify, 59
- antigen-binding sites, **482**, 482*f*
- results of binding with antibodies, 487–488, 488*f*
- antigen-presenting cells (APCs), 485, **489**, 490*f*, **494**–495, 494*f*, 495*f*
- activated macrophages as, **490**, 490*f*
- dendritic cells as, 476*f*, **490**, 490*f*
- antigenic determinants (epitopes), **481**, 481*f*, 487, 487*f*
- antigenic drift, **693**–694
- antigenic shift, **374**–375*b*, **693**
- bird flu and, 374*b*, 693, 693*t*
- influenza virus and, **374**–375*b*, 375*f*, **693**, 693*t*
- antigenic variation, **435**
- gonorrhea and, 435, 749
- HIV and, 541–542
- Opa-encoding gene and, 435
- as pathogenic mechanism, 435, **447*f***
- used by *Giardia* protozoa, 446
- used by *Trypanosoma*, 435, 446
- used by trypanosomes, 435, 446, 629, 629*f*
- vaccine development and, 509, 511
- antigens, **59**, 480, **481**, 481*f*
- allergens and, **523**
- antibody-antigen binding results, **487**–488, 488*f*
- antigenic variation and, 435
- binding sites, **479**, 479*f*, 480*f*
- cytotoxicity and, 487, **488**, 488*f*
- early discoveries about, 480
- endogenous, **493**
- epitopes and, **481**, 481*f*, 484
- extracellular (free), B cell activation and, 482, 482*f*
- fluorescence microscopy and, 59
- free (extracellular), 482
- H antigen, **82**
- haptens and, **481**, 481*f*
- histocompatibility complex and, **482**, 482*f*, 500*f*, **533**–534
- neutralization by antibodies, 487, **488**, 488*f*
- number recognized by human immune system, 484
- O polysaccharide functioning as, 86
- opsonization by antibodies, 484, **485**, 485*f*
- primary immune response to, **497**, 497*f*
- secondary immune response to, **497**, 497*f*
- superantigens, **439**, 441*t*, 492, 527
- T antigen, **393**
- T-cell receptors and, 480
- T-dependent, **482**, 482*f*
- T-independent, **484**, 484*f*, 503
- as vaccines, **495**
- antihelminthic drugs, 564*t*, 571–572
- antihuman immune serum globulin (anti-HISG), **518**, 520*f*
- antimetabolites, 561*f*, 563–564, 565*t*, 573
- antimicrobial agents, 192–202
- alcohols, 194–195, 194*t*, 201*t*, 202*t*
- aldehydes, **197**, 202*t*
- antibiotic resistance, triclosan and, 192
- biguanides, 193, 201*t*
- biofilms and, 161
- bisphenols, **192**–193, 193*f*, 201*t*
- cellular proteins damaged by, 184
- Cepacol, 196, 202*t*
- chemical food preservatives, 197, 202*t*
- chemical sterilization, 198–199, 202*t*
- chlorhexidine, 193, 201*t*

- chlorine, 193–194, 193f, 202t  
copper, 195–196, 195f, 202t  
death rates and, 183, 183t, 184f  
detergents, 196, 196f, 202t  
drawbacks of, 12  
effectiveness of, factors  
    influencing, 183  
ethylene oxide, 198, 202t  
evaluating, 195, 196f  
glutaraldehyde, 197, 201t, 202t  
halogens, 193–194, 202t  
heavy metals, 195–196, 195f, 202t  
hexachlorophene, 192, 193f, 201f  
in household cleaning products, 18, 196–197  
hydrogen peroxide, 202  
iodine, 193–194, 201t, 202t  
mechanisms of action, 183–184  
mercury, 195, 202t  
microbial exponential death rate and, 183, 183t  
    microbial death curve, 184f  
nitrites/nitrites, 197, 202t  
ozone, 199, 202t  
peracetic acid, 199, 202t  
peroxygens, 199, 202t  
phenol/phenolics, 192, 193f, 201t  
plasma membrane damaged by, 90, 183–184  
plasma sterilization, 198–199, 202f  
quats, 90, 193f, 196–197, 196f, 200, 201t, 202t  
resistance  
    to biocides, 202–203, 203f, 203t  
    biofilms and, 17, 18f  
    emerging infectious diseases (EIDs) and, 18–20  
    misuse/overuse of, 18, 19, 415, 575–578, 576f, 583b  
    porins and, 202  
    silver, 195–196, 195f, 202t  
    silver nitrate, 195, 202t  
    silver-sulfadiazine, 195, 202t  
    soaps, 196, 196f, 202t  
    summary (agent/mechanism of action/preferred use), 201t–202t  
    supercritical fluids, 199, 202t  
    surface-active, 192, 193f, 196–197, 196f, 201t, 202t  
    Surfactine, 195  
    terminology of, 182, 183t  
    triclosan, 192–193, 193f, 201t, 566  
    Zephiran, 195, 196, 196f, 198b, 202t  
    zinc, 196  
antimicrobial drugs, 197, 558–588. *See also* antibiotics  
    bactericidal vs. bacteriostatic, 555  
    commonly used, 564–565t, 566t  
    future of, 578–579  
    history of, 559–560  
    microbes that produce, 245, 247, 317, 320, 341, 559, 560t, 563  
    modes of action, 561f–564f, 562–564, 564–565t  
    spectrum of activity and, 560–561, 562t  
    susceptibility/sensitivity tests, 572, 572–573, 573f  
antimicrobial peptides (AMPs), 473–474, 474t, 585  
antimicrobial resistance. *See* antibiotic resistance  
antimicrobial substances of innate immunity, 466–473  
    antimicrobial peptides, 473–474, 474t, 578–579  
    complement system, 466–470, 474t  
    interferons, 471–473, 474t  
    iron-binding proteins, 473, 474t  
    as second line of defense, 452, 452f, 466  
antimycobacterial antibiotics, 564t, 569  
antiprotozoan drugs, 12, 528, 529f, 564t, 577  
antiretroviral drugs, 553, 575  
antiseptic agents, 579  
antisense DNA, explored as gene therapy, 258  
antisense DNA technology, MacGregor tomatoes, 267, 267t  
antisense drugs, 658  
antisense strand (- strand), 388, 389f  
antiseptic, 182, 183t  
antiseptics, 190–201  
    alcohols, 194–195, 194t, 201t, 202t  
    alexidine, 193  
    bacitracin, 560t, 563, 566–567  
    bacteria able to grow in, 196–197, 196f  
    biguanides, 193, 201t  
    bisphenols, 192–193, 193f, 201t  
    Cepacol, 196, 202t  
    chloramines, 194  
    chlorhexidine, 193, 201t  
    chlorine dioxide, 194, 198  
    chlorine gas, 194  
    copper, 195–196, 202t  
    effectiveness of various, 196, 196f  
    halogens, 193–194, 202t  
    heavy metals, 195–196, 195f, 202t  
    hexachlorophene, 192, 193f  
    iodine, 193–194, 201t, 202t  
    iodophors, 193  
    isopropanol, 195  
    Lysol, 192  
    mercuric chloride, 195  
    mercury, 195, 202t  
    phenols/phenolics, 192, 193f, 201t  
    pHisoHex, 196  
    Purell, 195  
    quats, 90, 193f, 196–197, 196f, 200, 201t, 202t  
    silver, 195–196, 195f  
    silver-sulfadiazine, 195, 202t  
    soap and, 196  
    Surfactine, 195  
    triclosan, 192–193, 193f, 201t, 566 vs. disinfectants, 182  
    Zephiran, 195, 196, 196f, 198b, 202t  
    zinc, 199  
antiserum, 286, 498, 498f, 616  
antitoxins, 438, 479, 508, 517  
    neutralization tests and, 517, 518f  
antitrypsin, 259t  
antitumor activity of oncolytic viruses, 371  
antitumor drugs, nucleoside analogs as, 226–227, 227f  
antitumor (oncolytic) viruses, 371  
antiviral drugs, 566t, 575–577, 576f  
    acylovir, 562t, 569, 570f  
    AZT and, 227  
    interferons and, 471–473, 471f, 566t  
    nucleoside/nucleotide analogs and, 226–227, 227f, 575  
antiviral proteins (AVPs), 471–473, 471f  
ants  
    fire, 348  
    fungi-farming, 332  
APCs. *See* antigen-presenting cells  
aphids  
    cauliflower mosaic virus transmitted by, 396t  
    potato yellow dwarf virus transmitted by, 396t  
Apicomplexa, 351–353, 352f, 356t  
    fire ant egg production and, 348  
    oocysts of, 352  
aplastic anemia, chloramphenicol causing, 565  
apoenzyme portion of enzymes, 114, 114f  
apoptosis, 457t, 493, 493f, 494f  
apple juice, contaminated, DNA fingerprinting to track, 261, 263f  
*Approved Lists of Bacterial Names*, 283  
APTIMA assay, 551  
*Aquaspirillum serpens*, plasma membrane of, 89f  
aquatic environments  
    algae's importance to, 348  
    bacteria found in, 304, 305f, 309, 312  
aquatic microbiology, 782–795  
    aquatic microbes, 782–784  
    sewage treatment, 789–795  
    water quality and, 784–787  
    water treatment, 788–789  
aquatic microorganisms, 782–784  
    freshwater, 782–783  
    seawater, 783  
aqueous solutions  
    of ethanol, 194–195  
    ethanol and water, 195  
    formalin, 197  
    vs. tinctures as antiseptics, 193–194, 194f  
    Zephiran and water, 195  
aquaporins, 91f, 92  
Arachnida (class), 363, 364t  
arachnoid mater, 616, 617f  
arboviral disease, as nationally notifiable infectious disease, 424t  
arboviral encephalitis, 364t, 630–632, 632f  
    *Culex* mosquito as vector, 364t, 413t  
    eastern equine encephalitis in humans, 625  
    horses affected by, 625  
    St. Louis encephalitis (SLE), 625–626  
    symptoms, 625  
    types of, 628b  
    western equine encephalitis in humans, 625  
arboviruses, 220b, 388, 634b  
    encephalitis caused by, 630–632, 632f, 634b  
arbuscules, 773, 774f  
*Arcanobacterium phocae*, found in wounded seals, 282b  
archaea, 4, 274–275, 274f, 276t, 302t, 326, 326f  
    acidophilic, 326  
    cell walls of, 4, 87, 274, 276t, 326  
    evolution and, 275, 275f, 277, 277f, 280f  
    extremophiles of, 326. *See also* extreme halophiles; extreme thermophiles  
    Gram staining and, 87  
    halophilic, 78  
    morphology of, 87, 326, 326f  
    nitrifying, 326  
    nutritional requirements of, 4, 326  
    origins of, 275, 275f, 277, 277f, 280f  
    thermophilic, optimum growth temperature and, 156, 326  
Archaea (domain), 4, 274–275, 274f, 276t, 300, 302t, 326, 326f  
    Bacteria Domain vs., 276t  
    Eukarya Domain vs., 276t  
    extreme halophiles of, 4, 274, 274f, 280f, 326  
    extreme thermophiles of, 4, 156, 274, 274f, 280f, 302t, 326, 326f  
    gram-negative genera, 302t  
    gram-positive genera, 302t  
    methanogens, 4, 274, 274f, 280f, 302t, 326  
    phylogenetic relationships, 274f, 280f  
Archaezoa, position in evolutionary tree, 274f  
Arenaviridae, 378t  
Arenavirus, 354b, 378t, 659–660  
Argentine hemorrhagic fever, 666  
Arginine (Arg), 42t  
arithmetic death curves, vs. logarithmic calculations, 184f  
armadillos  
    as disease reservoir, 667  
    used to culture *M. leprae*, 163, 619  
aromatic amines, formed in high-heat cooking, 231b, 232b  
arsenic/arsenic derivatives, 12, 117, 118  
arsenic, as an enzyme poison, 118  
artemisinin, 577, 671  
artemisinin-based combination therapies (ACTs), 577, 671  
artery plaque, acoustic microscopy to study, 61, 62f, 66t  
arthritis  
    gonorrheal, 755  
    psoriatic, 538  
    rheumatoid, 463, 492, 499b, 512, 532, 533  
    septic, *Haemophilus influenzae* causing, 312  
arthroconidia, 334–335, 335f, 340t  
    in *Coccidioides immitis*, 334f, 335  
*Arthroderma* (*Trichophyton*), 340t  
arthropods, 330, 331f, 363, 364t  
    *Alphavirus* transmitted by, 377t  
    lice and pediculosis, 608–609, 608f  
    mites and scabies, 597b, 607–608, 608f  
    mosquitos and West Nile virus, 19, 212, 220b, 220f, 626  
    as vectors, 331f, 363, 363f, 364t

diseases they transmit/causative agent, 413*t*  
transmission methods, 413–414, 414*t*  
viruses that can replicate in, 378*t*  
arthroscopic surgical instruments, sterilizing, 198–199  
Arthus reactions, 528*t*  
artifacts  
mesosomes as, **90**  
specimen preparation and, 63  
artificial blood, genetically modified pigs and, 258  
artificial blood vessels, 263  
artificial selection, **247**  
artificially acquired immunity  
active, 494*f*, **495**. *See also* vaccination  
passive, 494*f*, **495**  
ascariasis, 364*t*, 738*f*, 740*b*, **741**, 742*f*  
*Ascaris*, 360  
*Ascaris lumbricoides*, 360, 364*t*, 738*f*, 741, 742*f*  
Asclepius, 14, 14*f*  
ascomycetes, 337, 338*f*  
Ascomycota (sac fungi), 279*f*, **337–338**, 338*f*, 340*t*  
ascorbic acid (vitamin C), fermentation and, 134*t*  
ascospores, **338**, 338*f*  
ASCs (adult stem cells), 540  
ascus, **338**, 338*f*  
asepsis, **182**  
aseptic encephalitis, 220*b*  
aseptic packaging, hydrogen peroxide and, 199, 801–802, 802*f*  
aseptic techniques, **8**, 9*f*, 182, 415, 417  
asexual reproduction  
in algae, 344, 345*f*  
in diatoms, 345*f*  
in *Plasmodium vivax*, 351, 352*f*  
asexual spores, **334–335**, 335*f*, 336*f–339f*, 340*t*  
of prokaryotic actinomycetes, 320  
Asian liver fluke (*Clonorchis sinensis*), 357, 358*f*  
asparagine (Asn), structural formula/characteristic R group, 42*t*  
aspartic acid (Asp)  
structural formula/characteristic R group, 42*t*  
in transamination, 145*f*  
aspergillosis, 341, 569, **704**  
*Aspergillus flavus*, aflatoxin produced by, 227, 445  
*Aspergillus fumigatus*, 704  
*Aspergillus* genus/spp., 334, 335*f*, 340*t*, 341, 452*b*  
caspofungin (Cancidas) to treat, 574  
fermentation and, 134*t*  
food processing temperatures, sclerotia and, 795  
pneumonia caused by, 452*b*  
triazole antifungals to treat, 574  
used in production of sake, 800  
*Aspergillus niger*, 333*f*, 335*f*  
genetically modified rennin and, 267*t*  
used to produce citric acid for food/beverages, 341  
aspirin, 440, 465

asthma, 528, 528*t*  
as an allergic reaction, 530  
hygiene hypothesis and increase in, 530  
leukotrienes and, 529  
atazanavir, 553, 576  
atherosclerosis, 16  
athlete's foot (tinea pedis), 568, 575, **605**, 606*f*  
Atlantic coast horseshoe crab, 441  
atmospheric oxygen levels  
photosynthetic cyanobacteria and, 320–321  
photosynthetic planktonic algae and, 348  
atomic force microscope (AFM), 58*f*, **64**, 64*f*, 67*t*  
antibody molecules shown by, 482*f*  
atomic number, **26**  
of common elements, 27*t*  
atomic weight, **26**  
of common elements, 27*t*  
atoms, **26–27**, 27*f*  
chemical elements and, 26–27, 27*t*  
molecule formation by, 27–31  
structure of, 26, 26*f*  
ATP  
in active membrane transport processes, 91, **93**  
anabolic reactions and, 112, 112*f*  
breakdown of, 112, 112*f*  
in Calvin-Benson cycle, 138, 140*f*  
catabolic pathways and, 112, 112*f*, 119, 121  
chemiosmotic generation of, 129–130, 129*f*  
distributions/concentration of, confocal microscopy and, 60  
generation of, 120–121  
glycolysis and, 122–125, 123*f*  
high energy bonds of, 119, 120  
metabolic pathways and, 121  
microbial uses for, 144  
mitochondria's role in production of, 103  
oxidation-reduction reactions and, 120, 120*f*, 121*f*  
photophosphorylation and, 123  
in photosynthesis, 138, 139*f*  
requirements for production of, 139, 141*f*  
structure of, 47–48, 48*f*  
synthesis of, 112, 112*f*  
nitrogen requirements, 158  
phosphorus requirements, 158  
viruses and, 370, 370*t*  
volutin to synthesize, 95  
yield in fermentation, 132*f*, 133*f*, 135*t*  
yields from aerobic respiration, 130*t*, 131*f*, 135*t*  
yields from anaerobic respiration, 130, 135*t*  
ATP synthase, 128, 128*f*, 129*f*  
atrichous bacteria, **81**  
Atripla, 553, 575  
attachment (adsorption) stage in viral multiplication  
in animal viruses, **385**, 389*f*  
in bacteriophages, **381**, 382*f*, 385*t*  
attenuated killed vaccines, **507**

attractants (chemotactic signals), 82  
atypical pneumonia, 692, 693  
AUG codon as start codon, 216  
Augmentin, 568  
auramine O, 59  
Aureomycin (chlortetracycline), 565  
mode of action/spectrum of activity, 562*t*  
produced by produced by  
*Streptomyces aureofaciens*, 560*t*  
*Australian bat lyssavirus* (ABLV), 630  
autism, MMR vaccine and, 506, 507*t*, 511, 598  
autoclaves/autoclaving, **185–187**, 191*t*  
container size and effectiveness of, 185, 186*t*  
endotoxins and, 442*b*, 442*t*, 444*b*, 446*b*  
prions not inactivated by, 200  
sterilization indicators, 187, 187*f*  
temperature/pressure relationships in, 185, 186*t*  
autografts, **540**  
autoimmune diseases, **536–538**. *See also* specific disease  
cell-mediated, **538**  
cytotoxic, **537**  
immune complex reactions, **537**  
self-tolerance loss and, 537  
autoinoculation, 593  
autotrophs (lithotrophs), **140–141**, 141*f*, 144  
auxotroph mutants, **229–230**, 229*f*  
Avery, Oswald T., 10*f*, 15, 47, 232  
avian influenza A H5N1 (bird flu), **18**, 374–375*b*, 700, 700*t*  
emerging infectious diseases and, 18, 418, 419*t*  
genetic recombination and, 418, 693  
recent human cases, by subtype/location, 374*t*  
vaccines and, 18  
avian influenza A (H5N1) virus  
emerging infectious diseases and, 18, 418, 419*t*  
genetic recombination and, 418, 693  
avian sarcoma viruses, 393  
avirulent microbial strains  
defined, 11  
vaccines produced from, immunity and, 11  
avoparcin, 583*b*  
AVPs (antiviral proteins), **471–473**, 471*f*  
axial filaments (endoflagella), **82**, 83*f*, 325, 325*f*  
azelaic acid (Azelex), 599  
azidothymidine (AZT), as nucleoside analog, 227  
azithromycin, 565*t*, **571**, 610  
azlocillin, 568  
azole antibiotics, 566*t*, **574**, 574*f*  
*Azolla*-cyanobacteria symbiosis, 779, 779*f*  
*Azomonas* genus/spp., 301*t*, **309**  
*Azospirillum* genus/spp., 300*t*, **303–304**  
*Azotobacter* genus/spp., 95, 301*t*, **309**  
AZT (azidothymidine), as nucleoside analog, 227  
aztreonam, 564*t*, 569

## B

β-1, 4 linkage, 85*f*  
B cells, **458**, 478, 478*f*, **480**, 486*f*  
activation of, 485, 486*f*  
cancerous, 512, 513*f*  
clonal selection and, **485**, 486*f*  
in compromised hosts, 416  
differentiation of, 485, 486*f*  
humoral immunity and, 485–487, 486*f*, 487*f*  
IgD antibodies and, 483*t*, 484  
IgM antibodies and, 485  
lymph node location of, 458, 638, 639*f*  
as memory cells, **485**, 486*f*, 497, 497*f*  
monoclonal antibodies and, 512, 513*f*, 514  
as plasma cells, **485**, 486*f*, 494  
processes of, 478*f*  
spleen and, 494*b*  
T-dependent antigen and, 485, 500*f*  
as third line of defense, 452*f*  
β-galactosidase, 219–222, 221*f*, 222*f*  
β-galactosidase (*lacZ*) gene, 221*f*, 223*f*, 249, 249*f*, 255, 255*f*  
encoding as marker gene, 249*f*  
β-lactam antibiotics, gram-negative bacteria susceptibility and, 88*b*  
B lymphocytes. *See* B cells  
B vitamins, complex culture media and, 163  
*Babesia* genus/spp., 330  
*Babesia microti*, 352, 356*t*, 673  
babesiosis, 356*t*, 364*t*, **656b**, **673**  
BAC (bacterial artificial chromosome), 260*f*  
Baccillariophyta, 345*t*  
Bacillales, 301*t*, **315–316**, 315*f*  
bacillary dysentery. *See* shigellosis  
*Bacillus amyloliquefaciens*, BamHI restriction enzyme in rDNA technology, 248*t*  
*Bacillus anthracis*, 25*f*, **315**, 441*t*, 650–652  
as biological weapon, 315, 652, **654b**, 654*f*  
capsule of, 43*b*, 80, 433  
Clinical Case, 26*b*, 43*b*, 44*b*, 48*b*  
emerging infectious diseases and, 419*t*  
fluorescein isothiocyanate to stain, 59  
Koch's experiments with, 11, 406, 650  
portals of entry and, 431, 432  
reservoirs/transmission method, 413*t*  
toxins of, 235, 441*t*, 650  
virulence and, 80, 432, 433, 650–652  
bacillus/bacilli, 77, 77*f*, 106*b*, 315–316, 315*f*  
*Bacillus Calmette-Guérin* (BCG) vaccine, 626, 685  
*Bacillus cereus*, 315, 315*f*  
endospore staining and, 70*f*  
gastroenteritis caused by, 315, **726–727**, 728*b*  
refrigerator temperature and growth of, 156*f*  
*Bacillus coagulans*, capable of growth in canned foods, 795



- Bacillus* genus/spp., 78, 78f, 301t, 315–318, 315f
- anaerobic respiration and, 130
  - antibiotics produced by, 315
  - calcium propionate active against, 197
  - endospores and, 95–97, 96f, 301t
  - enzymes of
    - bioremediation and, 16
    - in household detergents, 16
  - fermentation and, 132f
  - in fossilized amber, PCR and, 290
  - genetic transformation natural occurring in, 233
  - as gram-variable bacteria, 86
  - lipid inclusions of, 95
  - selenium toxicity and
    - nanotechnology, 263, 263f
- Bacillus licheniformis*, binary fission in, 168f
- Bacillus sphaericus*, survived in fossilized amber for millions of years, 277
- Bacillus subtilis*, 78f
- bacitracin derived from, 560t
  - genetic engineering and, 256
  - pentose phosphate pathway and, 125
- Bacillus thuringiensis*, 315–316, 315f
- BT toxin and, 264, 266, 267t, 315–316, 315f, 806
  - human allergic reactions to, 266
  - monarch butterflies and, 266
  - Pseudomonas fluorescens* modified to produce BT toxin, 266, 267t
  - sold industrially, 806
- bacitracin, 561f, 564t, 569
- bactericidal antimicrobial drugs, 561
- bacteremia, 409
- as emerging infectious disease, 419t
  - methicillin-resistant *Staphylococcus aureus* and, 419t
  - nosocomial, 417t
  - epidemiological analysis of, 423b
  - vancomycin-resistant enterococci and, 419t
  - vancomycin-resistant *Staphylococcus aureus* and, 419t
- bacteria/bacterium, 2, 3–4, 5f, 75–97, 299–326
- acetic-acid producers, 300t
  - acid-fast, 69, 70f, 71t, 87–88
  - staining and, 69, 70f, 71t
  - Ames test uses to identify genotoxins, 230–231, 230f, 232b
  - anatomy, 3–4, 79f
  - atypical, 87–88
  - cell walls, 84–88, 85f
  - damage to, 88
  - size/shape/arrangement, 76–78, 79f
  - structures inside cell wall, 79f, 88–97
  - structures outside cell wall, 78–84, 79f
  - antibiotic resistance. *See* antibiotic resistance
  - beneficial activities of, 15–16
  - biochemical tests and, 135–137, 137f, 284–287
  - biofilms, percentage existing in, 77. *See also* biofilms
  - bioremediation and, 16, 32b
  - as carbon recyclers, 15
  - as carcinogen indicators, 230–231, 230f
  - as chemoheterotrophs, 141f, 143
  - classification of, 278–280, 279f
  - cotton production and, 3b, 38
  - as domain, 6, 274, 274f, 276t
  - as domain in three-domain system, 273
  - early representations, 6, 7f
  - emerging infectious diseases caused by, 419t
  - endospores formed by. *See* endospores
  - evolution of, 274, 274f, 276t, 277, 277f
  - fermentation and, 8, 123f, 130–133, 134t
  - first used in genetic research, 15
  - flagella of. *See under* flagella
  - food spoiled by, vs. by molds, 341
  - in foodstuffs, radiation doses needed to kill, 797t
  - fungi vs., 332, 333t
  - genetic recombination in, 231–239
  - genetic transformation in, 232–233, 233f, 234f
  - germ theory of disease and, 8, 11, 477
  - giant, 301t, 314–315, 315f, 326
  - glycocalyx of, 79f, 80
  - gram-negative, 68f, 69, 85f, 86, 87t
  - gram-positive, 68f, 69, 84, 85f, 86, 87t
  - gram stain mechanism and, 86
  - identification methods, 281–294
    - by cell morphology, 284
    - by differential staining, 284
    - by rapid identification methods, 285–286, 285f
    - by serology, 286–287, 286f, 287f, 288f
  - L forms of, 88
  - metabolism, 111–152. *See also* metabolism (microbial)
  - monomorphic, 78
  - movements of, 81–82, 82f
  - mutations in, 20b
  - as nitrogen recyclers, 15
  - nutritional classification of, 4, 140–143, 141f
  - oil-eating, 32b
  - origin of, 274, 274f, 276t, 277, 277f
  - osmotic solutions and, 92–93, 92f
  - parasitic, 403
  - pasteurization process and, 8
  - as pest controllers, 16
  - pH of, 67
  - pH range and growth of, 156
  - photosynthetic. *See* photosynthetic bacteria
  - plasma (cytoplasmic) membrane, 89–91, 89f
  - pleomorphic, 78
  - quorum sensing and, 56b, 160, 161
  - rapid identification tests for, 285–286, 285f
  - reproduction in, 4, 168, 168f
  - resistance to chemical biocides, 200, 200f
  - scientific nomenclature and, 278
  - shapes of, 4, 5f, 77–78, 77f, 78f
  - genetics and, 78
  - shrinkage/collapse of, 93
  - size of, 14, 77, 100t
  - specimen preparation for
    - microscopy, 64, 67
  - staining of, 67–71, 71t
  - strains of, 280
  - symbiotic, 106, 106b, 266, 300t
  - in taxonomic hierarchy, 279, 279f
  - thermoduric, 187
  - thermophilic, 182
  - used experimentally to identify mutants, 228–230, 229f, 230f
  - virulence of, 70, 80
  - viruses compared to, 370, 370t
- Bacteria (domain), 274f, 279–280, 279f, 280f, 300
- Archaea Domain vs., 276t
  - Eukarya Domain vs., 276t
  - phylogenetic relationships and, 273–277
  - prokaryote classification and, 278–280
  - selected phylums/genera/special features, 300t–302t
- bacterial artificial chromosome (BAC), 260f
- bacterial biosensors, 780b
- bacterial chromosomes, 94
- maps, 212, 212f
- bacterial cultures (growth of)
- bacterial division, 168, 168f
  - generation times, 168–169, 169f
  - growth curves, 170–171, 170f
  - obtaining pure, 167, 167f
  - phases of growth, 170–171, 170f
  - preserving, 167–168
- bacterial diseases
- of cardiovascular system, 645–662
  - of digestive system, 713–727
  - of eyes, 609–611
  - of lymphatic system, 645–662
  - of nervous system, 617–626
  - of reproductive system, 747–756, 759b, 761b
  - of respiratory system, 683–685, 687–698
  - of skin, 591–600
  - of urinary system, 746–747, 748b
- bacterial endospores, vs. other spores, 97
- bacterial enzymes
- bioremediation and, 16
  - as restriction enzymes in rDNA technology, 247, 248t
- bacterial growth curve, 169f, 170–171, 170f
- bacterial meningitis, 617–619, 623b
- Clinical Case, 300b, 317b, 318b, 320b, 324b
  - Hib vaccine and, 613, 614
- bacterial morphology, genetics and, 78
- bacterial pneumonias, 692–697. *See also* specific pneumonia
- atypical vs. typical pneumonia, 692, 693
- summary (by pathogen/symptom/reservoir/diagnosis/treatment), 695t
- bacterial vaginosis, 762–763, 763f, 766b
- bacterial viruses. *See* bacteriophages
- bacterial zoonoses, 413t
- bactericidal antimicrobial drugs, 561
- bacteriochlorophylls, 138, 143, 143t
- bacteriocins, 310
- microbial antagonism and, 403–404
  - Nisin and, 197, 578
  - produced by *Escherichia coli*, 310, 403, 456
- Bacterioidetes, 322
- Bacteriological Code, 278
- bacteriology, 12, 14
- bacteriophage f2, size of, 372f
- bacteriophage lambda, 376f
- lysogenic cycle and, 383–385, 383f
- bacteriophage M13, size of, 372f
- bacteriophage MS2, size of, 372f
- bacteriophage T4, size of, 372f
- bacteriophages (phages), 234–235, 237f, 287, 289f, 371, 442
- as complex virus, 374, 376f
  - cultivation of, 374, 376, 376f, 379
  - lysogeny, prophages and, 442
  - multiplication of, 381–385, 382f–384f, 385t
  - vs. animal viruses, 385t
  - pathogenicity coding and, 442
  - phage DNA, 234–235, 247, 381, 382f, 383f, 385t
  - phage libraries, 253, 253f
  - phage lysozyme, 381
  - phage therapy, 371, 579
  - phage typing, 287, 289f
  - reproduction and, 234–235, 237f
  - restriction enzymes and, 247
  - sizes of selected, 372f
  - T-even bacteriophages, 374f, 381–383, 382f
  - transducing, 234–235, 237f
  - viral plaques formed by, 376, 376f
- bacteriostasis, 182
- bacteriostatic antimicrobial drugs, 561
- Bacteroidales, 302t
- Bacteroides* genus/spp., 302t, 322
- deep tissue infections and, 322
  - gingival crevices inhabitants, 322
  - as normal microbiota of large intestine, 322, 404t
  - as normal microbiota of mouth, 404t
  - as normal microbiota of urethra, 404t
  - phylogenetic relationships, 280f
- Bacteroidetes, 302t, 322
- baker's yeast. *See* *Saccharomyces cerevisiae*
- bakery products, microbes used in, 800
- Balamuthia*, 351, 356t, 623b, 635
- balantidial dysentery, 356t
- Balantidium coli*, 353, 356t
- Baltimore, David, 10f
- BamHI restriction enzyme, 248t, 249f
- bandages, quat antiseptics neutralized by, 199, 201b
- Bang, Olaf, 392
- Barr, Yvonne, 10f, 393
- Barré-Sinoussi, Françoise, 13t
- Bartonella* genus/spp., 300t, 305

- Bartonella henselae*, 305  
cat-scratch disease and, 305, 413*t*, 419*t*, **653**–654, 653*f*, **655b**  
disease reservoir for, 413*t*  
transmission due to, 413*t*
- basal body  
eukarotic cell, 98*f*  
of flagella, 81, 81*f*
- base pairs, **208**
- base sequences of chromosomes, 209
- base substitutions (point mutations), **224**–225, 224*f*
- basement membrane, 590
- baseplate, of a T-even bacteriophage, 374*f*, 382*f*
- bases  
changes in sequencing of, 223. *See also* mutations  
complementary, 46*f*, 47, **208**  
in nucleotides, 46*f*, 47
- bases vs. acids, **34**–36, 34*f*, 35*f*
- basic dyes, 67
- basidiomycetes, **338**, 339*f*
- Basidiomycota (club fungi), **338**, 339*f*, 340*t*
- basidiospores, **338**, 339*f*
- basidium, **338**, 339*f*
- basiliximab, 542
- basophilic inclusion bodies, 443, 445*t*
- basophils, **456**, 457*t*, **529**  
histamine present in, 464  
in hypersensitivity reactions, 529, 529*f*  
IgE antibodies and, 481  
staining and, 456
- Bassi, Agostino, 9, 10*f*
- bathrooms, fungi capable of growing in, 336
- bats, 628–630, 631*b*, 631*f*  
as disease reservoirs, 413*t*, 630*footnote*  
fruit, possibly transmitting hemorrhagic fevers, 667*b*  
histoplasmosis and, 695–696  
rabies case report, **631b**, 631*f*  
rabies virus variant found in, 630, 631*b*, 631*f*
- Baylisascaris procyonis*, 360, 364*t*, 419*t*
- BCG (*Bacillus Calmette-Guérin*)  
vaccine, 626, 685, **691**
- Bdellovibrio*, 301*t*, **312**, 312*f*
- Bdellovibrionales*, 301*t*
- Beadle, George W., 10*f*, 13*t*, 15
- bears, as disease reservoirs, 413*t*
- Becton Dickinson's Enterotube II, 286*f*
- bee stings  
anaphylaxis and, 523–524  
desensitization success and, 526
- beef products  
infected with mad cow disease, 19  
tapeworms and, 358–359, 364*t*
- beer, **806**  
fermentation and, 8, 134*t*, 135*b*  
microbes used in production of, 806  
pasteurization of, 8, 187  
pasteurization time/temperature and, 187  
souring/spoilage, pasteurization and, 8
- Beggiatoa alba*, **307**, 772
- Beggiatoa* genus/spp. 143, 301*t*, **307**, 312, 772
- Beijerinck, Martinus, 15
- Beijerinckia* genus/spp., 300*t*
- benthic zone, **782**
- BenzaClin, 599
- benzalkonium chloride. *See* Zephiran
- Benzamycin, 599
- benzathine penicillin, 567, 568*f*
- benzoic acid, 202*t*
- benzopyrene, as frameshift mutagen, 227
- benzoyl peroxide, 160, 199
- Berg, Paul, 14
- Bergey, David, 281
- Bergey's Manual of Determinative Bacteriology*, 281
- Bergey's Manual of Systematic Bacteriology*, 278–279, 281*footnote*  
description of strains and, 285  
phylogenetic system as basis for, 299  
rRNA sequencing and basis for, 299  
selected prokaryotes from, 300–302*t*
- beta-hemolysis, 165, 165*f*
- beta-hemolytic streptococci, 165*f*, 317, 320*b*, 594–595  
group A (GAS), 317, 594–595, 595*f*, 640  
group B (GBS), 317, 320*b*, 324*b*, 640
- beta interferon (IFN- $\beta$ ), 259*t*, 471–473, 471*f*  
to treat multiple sclerosis (Betaferon), 473  
to treat osteoporosis (Actimmune), 473
- beta-lactam antibiotics, 567–569, 567*f*, 569*f*  
resistance to, 581
- beta-lactam ring in penicillins, 567, 567*f*
- beta-lactamases (penicillinases), 567, 568, 568*f*  
antibiotic inactivation and, 19*b*, 567, 568, 568*f*
- beta-oxidation  
in lipid catabolism, 134, 135*f*  
of petroleum/oil spills, 32*b*, 134
- Betadine, 193, 194
- Betaferon, to treat multiple sclerosis, 473
- betamethasone, 201*b*
- betaproteobacteria, 300–301*t*, 303, 305, **306**–307, 306*f*, 307*f*, 308*b*  
important genera/special features, 300–301*t*
- beverage industry, *Aspergillus niger* used in, 341
- bGH (bovine growth hormone), 266, 267*t*
- Bifidobacterium* genus/spp., as normal microbiota of large intestine, 404*t*
- biguanides, **193**, 201*t*
- bile, most microbes destroyed by, 430
- bile salts, gram-negative bacteria and, 86
- binary fission, 4, **76**, 100*t*, **168**, 168*f*, 276*t*  
of cyanobacteria, 321, 321*f*  
*Rickettsia* and, 304  
viruses and, 307*t*
- binomial nomenclature, **278**
- bioaugmentation, **781**
- biochemical oxygen demand (BOD), in sewage treatment, **789**
- biochemical reactions, metabolic, 111–152. *See also* chemical reactions
- biochemical tests, 135–137, 137*f*, 142*b*, 282*b*  
human pathogens isolated from marine mammals, 282*b*  
to identify microbes, 284–287, 284*f*–287*f*  
importance of, with enterics, 310
- biocides, **182**. *See also* antimicrobial agents
- biofilms and, 183
- bioconversion, **813**
- bioenhancers, uses in bioremediation, 32*b*
- biofilms, **17**, 18*f*, **56b**, **160**–161, 161*f*, **432**  
adherence and, 432–433  
antibiotic resistance and, 433  
antimicrobial resistance and, 183  
autoclaving, endotoxins and, 442*b*, 444*b*  
bacterial growth/survival and, 153, 598  
*Burkholderia* genus/spp. and, 444*b*, 689  
catheters and, 17, 18*f*, 154*b*, 161, 166*b*, 175*b*, 177*b*, 433, 586, 587*f*  
cystic fibrosis and, 161  
deep-sea hydrothermal vents and, 157*b*  
dental plaque as, 80, 432  
endocarditis and, 641*f*  
examples of, 432–433  
fimbriae's role in forming, 83  
gliding motility and, 83  
glycocalyx and, 80, 431–432  
group behavior in, 56*b*  
heart valves and, 161, 433, 641, 641*f*  
in hospital water supplies, 75  
inducer (signaling chemical) and, 56*b*  
*Legionella*, hospital water lines and, 689  
medical implants and, 17, 18*f*, 80, 537*b*  
*P. aeruginosa* can grow in, 462, 593  
*P. fluorescens* and indwelling catheters, 177*b*  
pathogenicity and, 432–433  
percentage of bacteria existing in, 76  
phagocyte evasion and, 462  
quorum sensing and, 56*b*  
resistance to antimicrobial agents and, 183, 433  
scanning acoustic microscopy and, 61, 62*f*, 66*t*  
in sewage treatment, 791, 792*f*  
that lead to disease, 56*b*, 433
- biofuels, **814**–815, 814*f*
- biogenesis theory, **8**
- biogeochemical cycles, 775–782  
carbon cycle, 775–776, 775*f*  
life without sunshine, 779–780  
microbial benefits to, 15
- nitrogen cycle, 776–779, 776*f*  
phosphorus cycle, **780**  
sulfur cycle, 779, 780*f*  
synthetic chemicals and, 780–782
- bioinformatics, **261**
- biological oxidation, 120, 121*f*. *See also* redox reaction
- biological transmission of disease (by arthropods), **414**, 414*t*
- biological weapons, 261, **654b**, 654*f*  
*Bacillus anthracis* as possible, 315  
bioweapons detectors, 190, 654*b*  
*Brucella* as possible, 650  
list of potential bioweapons (bacteria/viruses), 654*b*  
nanotechnology and, 263, 263*f*  
smallpox and, 601  
tularemia as possible, 654
- biology, molecular, **15**
- bioluminescence, **783**, 784*f*  
chemical pathway of, 56*b*
- bioluminescent bacteria, *Aliivibrio fischeri*, 56*b*
- biomass, **813**
- Bioquell, 199
- bioreactors  
algal, that could produce biofuels, 808, 814*f*  
in industrial fermentation, **808**–809, 809*f*
- bioremediation, **16**, **781**, 781*f*  
oil spills, 32*b*, 781
- biosafety level 4 (BSL-4) labs, 164–165, 165*f*
- biosensors (bacterial), 801  
to detect pollutants/pathogens, **786b**
- biosolids, 787
- biosynthesis, 144–146, 144*f*–147*f*  
metabolic pathway integration and, 146, 147*f*  
speed of, in eukaryotes vs. prokaryotes, 144
- biosynthesis stage in viral multiplication, **381**–383, 382*f*, 385*t*  
in DNA viruses, 385*t*, **386**–388, 387*f*, 388*t*  
in RNA viruses, 385*t*, **388**–391, 388*t*, 389*f*
- biosynthetic chemical reactions. *See* anabolism
- biotechnology, **16**, 244–271, **245**, **808**. *See also* recombinant (rDNA) DNA technology  
ethical issues, 266–267  
safety issues, 266–267  
tools of, 247–251  
artificial selection, **247**  
polymerase chain reaction (PCR), **249**–251, 250*f*  
restriction enzymes, **247**–248, 248*f*, 248*t*  
site-directed mutagenesis, **247**  
vectors, 248–249, 249*f*. *See also* vectors
- bioterrorism, **654b**. *See also* biological weapons  
bioweapons detectors, 190, 654*b*  
list of potential biological weapons, 654*b*

- biotin, 115*t*, 158  
biovars (biotypes), **286**, **311**  
bioweapons, 261, **654b**, **654f**  
detectors, 190, **654b**, **654f**  
potential pathogens list (bacteria/viruses), **654b**  
bird flu (avian influenza A/H5N1 influenza), **18**, 374–375*b*  
as emerging infectious disease, 18, 418, 419*t*  
genetic recombination and, 418  
vaccines and, 18, 374*b*  
birds  
as disease reservoirs, 340*t*, 413*t*  
influenza A virus subtypes and, **18**, 374–375*b*  
pet cockatiels and *Chlamydomyces psittaci*, 699*b*, 701*b*, 705*b*  
as West Nile virus disease reservoirs, 19, 220*b*, 413*t*  
Bishop, J. Michael, 13*t*, 393  
bismuth, *H. pylori* and, 69*b*  
bismuth sulfite agar, 165, 286*b*, 287*b*  
bisphenols, **192**–**193**, 193*f*, 201*t*  
endospores, mycobacteria and, 201*t*  
bites  
animal. *See* animal bites  
insect. *See* insect bites  
Black Death, 311. *See also* plague  
blades of algae, **344**, 344*f*  
blastomycosis, **335**, 335*f*  
*Blastomyces (Ajellomyces) dermatitidis*, 340*t*  
*Blastomyces dermatitidis*,  
blastomycosis caused by, 704  
blastomycosis, **704**, **706b**  
airborne transmission and, 412*f*, 413  
amphotericin B to treat, 568  
blastomycosis (North American blastomycosis), **704**, **706b**  
bleach (household)  
to disinfect drinking water, 194  
to disinfect norovirus, 201*b*  
mechanism of action, 462  
bleaching agents  
as disinfectants, 194  
safer, microbes and, 3*b*  
blebs/blebbing, 493, 494*f*  
blindness  
*Acanthamoeba* causing, 351  
herpetic keratitis causing, 605  
ophthalmia neonatorum causing, 610, 748  
trachoma causing, 322, 604–605, 605*f*  
blood, **456**, **644**, **645f**  
artificial, genetically modified pigs and, 258  
circulation of, 644, **645f**  
components  
formed elements, **456**–**458**, 457*t*, 638  
plasma, **456**  
filtration by kidney glomeruli, 529  
sepsis and, 646–647, 647*f*  
blood agar, 165, 165*f*  
blood banks  
hepatitis C and, 732–733  
safe blood supplies, 733*b*  
blood-brain barrier, **616**, 617*f*, 627  
blood capillaries, relation to lymphatic capillaries, tissue cells, 459*f*  
blood clotting  
fibrinogen and, 463  
in inflammatory response, 464*f*  
platelets' function as, 457*t*  
blood-clotting proteins, activated by endotoxins, 440  
blood diseases, 409  
blood-feeding insects, 330, 350, 667*f*, 668*b*  
arthropods, 19, 220*b*  
blood flukes, 356  
*Schistosoma*, 358, 364*t*, 666, 667*f*  
blood parasites (hemoflagellates), 330, 350, 667*f*, 668*b*  
blood plasma, **201**, **456**, **472b**, 638  
substitute, dextran as, 38  
blood platelets  
histamine present in, 464  
quinine and, 528, 529*f*  
thrombocytopenic purpura and, 528, 529*f*  
blood poisoning. *See* septicemia  
blood transfusions  
DiGeorge syndrome and, 554*t*  
hepatitis C and, 731*b*, 732–733  
HIV transmission and, 546  
reactions, 528*t*, 532–533, 532*t*, 533*f*, 544*t*, 554*b*  
Rh incompatibility, 532–533, 533*f*  
blood types, 532–533, 532*t*  
blood vessels  
artificial, 263  
in inflammatory response, 464*f*  
bloodborne parasites, 330  
bloodstream infections  
nosocomial infections and, 417*t*  
*P. fluorescens* (Clinical Case), 154*b*, 166*b*, 175*b*, 177*b*  
blooms, algal, **348**, **785**, 785*f*  
Blue cheese, ripened by *Penicillium* molds, 799  
blue-green algae, cyanobacteria  
misnomer, 320  
blue-white screening, 255, 255*f*  
blunt ends of cut DNA strands, **247**, 248*f*  
body defenses, 18. *See also* host defenses; immunity  
adaptive immunity, 435, **452**, 452*f*, **478**–**503**  
adaptive vs. innate, 452, 452*f*  
complement system, 466–470  
first line of defense, 452*f*, 453–456, 474*t*  
innate immunity, 451–477, **452**, 452*f*, **478**  
overview, 452*f*  
second line of defense, 452*f*, 456–472, **474t**  
antimicrobial substances, 466–474  
fever, 466  
inflammation, 463–466  
phagocytes, 460–463  
third line of defense, 452*f*  
body piercing, bacterial endocarditis and, 641  
body temperature  
fever and, 466  
high, intensifies interferon's effects, 471  
boil (furuncle), 463, 465, **593**  
boiling water, to control microbial growth, 185, 191*t*  
boils, 465  
acute inflammation of, 463  
Bolivian hemorrhagic fevers, **666**  
bonds, chemical. *See* chemical bonds  
bone marrow  
red, 458, 459*f*  
lymphocyte maturation and, 480  
bone marrow transplants, **541**  
bone morphogenic proteins, 259*t*  
booster immunizations, 418, 506*t*, 507, 508, 616  
Bordeaux mixture, 196  
*Bordetella bronchiseptica*, 282*b*  
*Bordetella* genus/spp., 300*t*, **307**  
*Bordetella pertussis*, 307, 504*f*, 687  
Clinical Case, 505*b*, 509*b*, 511*b*, 514*b*, 519*b*, 522*b*  
complement system evasion by, 470  
emerging infectious diseases and, 419*t*  
incubation period, 431*t*  
portals of entry, 431*t*  
vaccine, 506*t*, 507*t*, 687  
whooping cough caused by, 307, 419*t*, 424*t*, 431*t*, 687–688, 687*f*, 706*b*  
*Borrelia burgdorferi*  
Lyme disease caused by, 287, 288*f*, 413*t*, 419*t*, **656b**, **658**–**660**  
reservoirs/transmission method, 413*t*  
*Borrelia* genus/spp., 302*t*, **325**  
causing relapsing fever, 413*t*  
transmitted by *Ornithodoros* (tick), 413*t*  
Botox, 618–619  
bottlenose dolphins, 282*b*  
botulinal cook (12D treatment), **800**  
botulinum toxin, **439**, 616–617  
as A-B neurotoxin, 439, 441*t*  
bacteriophage genes and, 442  
botulism caused by, 441*t*, 622–625  
as an exotoxin, 442*t*  
glycoproteins, plasma membranes and, 90  
naming of, 438  
potency of, 432, 439, 442*t*  
serotypes of, 623–624  
symptoms induced by, 439, 441*t*, 622  
therapeutic uses (Botox), 624–625  
botulism, **441t**, **622**–**625**, **638b**. *See also* *Clostridium botulinum*  
diagnosis of, 624, 624*f*  
found in soil, 411, 622  
home canning methods and, 187, 622  
incidence of, 624  
infant, **624**  
as nationally notifiable infectious disease, 424*t*  
nitrites active against, 197, 202*t*  
refrigeration and, 618  
as special case of intoxication, 717  
symptoms, 439, 441*t*, 616–617  
treatment of, 624  
wound, **624**  
bovine growth hormone (bGH), 266, 267*t*  
bovine spongiform encephalopathy (BSE), 19, 200, 395, 419*t*, 636*f*, **637**  
bovine tuberculosis, **688**  
*Bradyrhizobium* genus/spp., 300*t*, **304**–**305**  
as symbiotic nitrogen fixers, 300*t*  
bradyzoites, in toxoplasmosis, 661, 662*f*  
brain, 611, 611*f*  
as immunologically privileged site, 534  
blood-brain barrier and, 611, **616**, 617*f*, 627  
parasitic helminths and, 364*t*  
pathogenic invasion routes to, 611  
prions and, 630–632, 630*f*  
brain abscess, caused by *Balamuthia*, 351, 356*t*, 623*b*, 629  
bread dough, what makes it rise, 133  
bread molds, 5*f*, 197, 335*f*, 337  
bread (rye), fermentation and, 134*t*  
breakbone fever, **665**  
breakthrough varicella, **597**  
breast cancer  
genetic screening and, 261  
monoclonal antibodies (Herceptin) to treat, 543  
breast milk, IgA antibodies in, 480, 481  
breathing, cellular respiration and, 122  
*Brevibacterium*, as normal microbiota of skin, 404*t*  
brightfield illumination, 57, 60*f*, 65*t*  
broad-spectrum antibiotics, **560**–**561**, 562*t*  
normal microbiota destroyed by, 555, 560  
bronchopneumonia, streptococcal, 409  
bronchiolitis, **687**  
bronchitis, **687**  
*Haemophilus influenzae* as cause of, 312  
bronchopneumonia, 693  
broth dilution tests, 578–579, 579*b*, 579*f*  
brown algae (kelp), **345**–**346**, **345t**  
*Brucella abortus*, 644, 650  
*Brucella* genus/spp., 300*t*, **305**  
adept at evading phagocytes, 462, 644  
brucellosis caused by, 305, 644  
portals of entry, 431*t*  
as potential biological weapon, 644, 650, **654b**  
reservoirs/transmission method, 413*t*  
*Brucella melitensis*, 644, 650  
*Brucella suis*, 644, 650  
brucellosis (undulant fever), 305, **649**–**650**, **655b**  
direct agglutination test to diagnose, 510  
disease reservoirs, 413*t*  
incubation period, 431*t*  
as notifiable infectious disease, 424*t*  
portal of entry, 431*t*  
portal of exit, 447



- transmission due to, 413*t*  
vaccine for animals, 644  
as zoonotic disease, 413*t*, 643  
Bruton's agammaglobulinemia, 544*t*  
BSE (bovine spongiform encephalopathy), 19, 200, 395, 419*t*, 636*f*, **637**  
BSL-1 to BSL-3 (biosafety level 1 to 3) labs, 165  
BSL-4 (biosafety level 4) labs, 164–165, 165*f*  
Bt (*Bacillus thuringiensis*-derived insecticidal toxin), 264, 266, 267*t*, 315–316, 315*f*, 813  
corn/cotton plants, 267*t*  
buboes, **644**  
  of bubonic plague, 657, 657*f*  
bubonic plague, **656b**, **657**, 657*f*  
budding bacteria, **168**, 304, 305*f*  
  *Hyphomicrobium* and, 300*t*, 304, 305*f*  
  planctomycetes and, 322  
budding viruses, **392**, 392*f*  
budding yeasts, **333**, 334*f*  
buffers (chemical), 35, 156  
  pH, **35**  
  temperature, water and, 34  
bugs  
  kissing, 350, 356*t*, 363*f*, 364*t*, 413*t*, 661  
  true, 364*t*  
bulking in sewage treatment, **791**  
  *Sphaerotilus* bacteria and, 306, 306*f*, 791  
bullae (lesions), **591**, 592*f*  
bullous impetigo, 593, 593*f*  
Bunyaviridae, **378t**  
*Bunyavirus*, 378*t*, 660, 667*b*  
*Bunyavirus*/CE virus (California encephalitis), 378*t*, 626, 626*f*  
*Burkholderia cepacia*, hospital equipment, disinfectants and, 306–307  
*Burkholderia* genus/spp., 300*t*, **306**–307, 429*f*  
  biofilms and, 444*b*, 444*f*  
  cystic fibrosis and, 306, 309  
  formerly grouped with  
    *Pseudomonas*, 278, 306  
  grow in disinfectants, 202, 306  
  resistance to chemical biocides and, 200, 306  
*Burkholderia pseudomallei*, 306–307, 697  
*Burkholderia (Pseudomonas) pseudomallei*, 278, 306, 690  
Burkholderiales, 300*t*  
Burkitt, Denis, 662  
Burkitt's lymphoma, 377*t*, 393, **649b**, 662–663, 663*f*  
burn patients  
  genetically modified epidermal growth factor to heal, 259*t*  
  nosocomial infection susceptibility and, 416  
  *Pseudomonas* infections and, 308  
  silver-sulfadiazine to treat, 567  
Burnet, Frank Macfarlane, 13*t*  
burning, as method of microbial control, 188, 191*t*  
bursa of Fabricius, **480**  
buruli ulcer, **597b**, **599**  
  identified as global health threat, 599  
butanediol, 132*f*  
butanol, 2, 132*f*, 134*t*  
butter, 806  
butterflies, Monarch, 266  
butyric acid, 132*f*  
by-products, metabolic pathways and, 121  
*Byssochlamys fulva*, produces heat-resistant ascospores, 795  
**C**  
C-reactive protein, 463  
C1 to C9 complement proteins, 466–470, 468*f*, 469*f*, 470*f*  
CA-MRSA (community-associated MRSA) infections, 21*b*, 581  
cabbage  
  fermentation and, 134*t*  
  lactic acid fermentation and, 134*f*  
cachectin, 437. *See also* tumor necrosis factor  
cadherin, 435  
calcium, enzyme inhibition and, 118  
calcium (Ca)  
  atomic number/atomic weight, 27*t*  
  as cofactor, 115  
  microbial growth requirements, 158  
calcium chloride solution, in genetic engineering, 251  
calcium hypochlorite (chloride of lime), 181, 194  
calcium ion, confocal microscopy to observe distributions/concentration of, 60  
calcium propionate, 197, 202*t*  
Caliciviridae, 377*t*  
California encephalitis (CE virus/*Bunyavirus*), 378*t*, 626, 626*f*, **628b**  
California sea otters, toxoplasmosis deaths, 282*b*, 662  
calves, colostrum and, 494–495  
Calvin-Benson cycle, **138**, 140*f*, 143, 144  
cAMP (cyclic AMP), **221**–222, 222*f*, 223*f*  
  amebae-produced, 353, 354*f*  
  camphor, bacteria that use as energy/carbon source, 235  
*Campylobacter fetus*, 313  
*Campylobacter* genus/spp., 301*t*, **313**  
  culturing, 164  
*Campylobacter jejuni*, 313, 583*b*, 583*f*  
  gastroenteritis caused by, **724**, 728*b*  
Campylobacteriales, 301*t*  
canarypox virus, carrying feline leukemia virus genes, 259*t*  
canarypox virus, carrying canine distemper virus genes, 259*t*  
cancer. *See also* carcinogens  
  acoustic microscopy to study, 61, 62*f*, 66*t*  
  activated macrophages destroy, 533*f*  
  adenocarcinomas, 392  
  AIDS-associated, 550*t*  
  antisense DNA explored as gene therapy, 258  
  breast, 261, 543  
  carcinogenic mutagens and, 230, 232*b*  
  cell transformation and  
    proliferation, 393, 542–543  
  cervical. *See* cervical cancers  
  colorectal (Clinical Case), 208*b*, 226*b*, 231*b*, 232*b*  
  cytotoxic T lymphocytes (CTLs)  
    destroy, 542, 543*f*  
  DNA mutations and, 226*b*  
  Epstein-Barr (EB) virus causing, 393  
  hepatitis B virus (HBV) causing, 393  
  immune system response to, 542–543, 543*f*  
  immunotherapy for, 542–543  
  interferons' discovery and, 14  
  interferons to treat, 472  
  interleukin-12 and, 499*b*  
  interleukins to treat, 259*t*  
  Kaposi's sarcoma, 20, 387, 472–473, 539, 542, 550*t*  
  liver, 393, 396*t*, 543  
  monoclonal antibodies to treat, 512  
  ovarian, 259*t*  
  *p53* gene and, 258  
  *Papillomavirus* and, 387  
  percentage known to be virus-induced, 393  
  prostate, vaccine and, 543  
  RNA interference (RNAi) and, 258  
  sarcoma, 392  
  skin, exposure to UV light and, 228  
  stomach, 313, 719  
  tumor cell transformation, 393, 542–543  
  vaccines, 543  
  viral therapy and, 371  
  viruses and, 377*t*, 384, 392–394  
Candida (caspofungin), 566*t*, **574**  
*Candida albicans*, 333, 335, 335*f*, 340*t*, 607*f*  
  antibiotics and overgrowth of, 403, 555  
  as budding yeast, 333, 601*f*  
  candidiasis caused by, 341, 606–607, 607*f*, 758–759, 759*b*  
  in diabetics, 601–602  
  in HIV/AIDS patients, 549, 550*t*, 601–602  
  incubation period, 431*t*  
  normal microbiota as defense against, 456  
  as normal microbiota of vagina, 404*t*, 751  
  nosocomial infections and, 416*t*  
  portals of entry, 431*t*  
  skin infections caused by, 445  
*Candida* genus/spp.  
  biofilms and, 161  
  as normal microbiota of large intestine, 404*t*, 758  
  as normal microbiota of mouth, 404*t*, 758  
  as normal microbiota of skin, 404*t*  
  as normal microbiota of vagina, 404*t*, 751  
*Candida krusei*, 606  
*Candida tropicalis*, 606  
candidiasis (yeast infection), 341, **606**–607, 607*f*, **765**–766, **766b**  
*Candida albicans* causing, 341, 606, 606*f*, 765  
caspofungin (Candida) to treat, 574  
fluconazole to treat, 606  
incubation period, 431*t*  
miconazole to treat, 606  
oral (thrush), 341, **601**, 601*f*, **765**  
portals of entry, 431*t*  
rash caused by, 594*b*  
vulvovaginal, 341, **765**  
candle jars, 164  
canine distemper vaccine, 259*t*  
canker sores, **603**  
canned foods  
  commercial sterilization and, **182**, 183*t*, 594*f*, **800**–801, 801*f*, 802*f*  
  heat-preserved, 185  
  home "canning", 185, 187  
  metal can construction, 802*f*  
  types of spoilage in, 800, 803*t*  
cannibalism, kuru and, 637  
Cano, Raul, 277, 290  
CAP (catabolic activator protein), 221–222, 222*f*, 223*f*  
*Capnocytophaga canimorsus*, 479*b*, 480*b*, 484*b*, 487*b*, 490*b*, 494*b*  
*Capnocytophaga* genus/spp., 302*t*  
capnophiles, **164**  
capsids (viral), **371**, 372*f*, 373*f*, 376*f*, 382*f*  
capsomeres, viral, **371**, 372*f*, 373*f*  
capsules (bacterial), 79*f*, **80**, 100*t*, **433**  
  antibodies and, 433  
  of *Bacillus anthracis*, 433  
  complement activation prevented by, 470  
  as examples of T-independent antigens, 484, 484*f*  
  of *Haemophilus influenzae*, 433  
  of *Klebsiella pneumoniae*, 433  
  of *Neisseria gonorrhoeae*, 307*f*  
  pathogenicity and, 433, **447f**  
  phagocytosis and, 433  
  staining of, 70, 70*f*, 71*t*, 80  
  of *Streptococcus pneumoniae*, 232–233, 233*f*, 433, 462, 508  
  vaccines that target, 508  
  virulence of pathogens and, 80, 232, 433, 462  
  of *Yersinia pestis*, 433  
carbapenem-resistant *Klebsiella pneumoniae*, 207  
carbapenems, 562*t*, **569**, 585*b*  
  penicillin allergy and, 530  
carbenicillin, 568  
carbohydrate catabolism, **122**–133, 123*f*  
  cellular respiration, 123*f*, 125–130  
  fermentation, 123*f*, 130–133  
  gas formation and, 136, 137*f*  
  glycolysis, 122–125  
carbohydrates, **37**–38  
  amphibolic pathways and, 146, 147*f*  
  microbes, photosynthesis and, 15  
carbolfuchsin stain, 68, 71, 71*t*, 88  
carbolic acid. *See* phenol  
carbon (C)  
  atomic number/atomic weight, 27*t*  
  bacterial recyclers of, 15  
  chemoheterotrophs and, 158  
  electron configuration, 28*t*  
  in methane formation, 30, 30*f*  
  microbial growth and, 158  
  in organic compounds, 36

- source of, microbes classified by, 139–140, 141f  
 structure of, 27f  
 uniqueness of, 34  
 carbon cycle, 775–776, 775f  
*Pelagibacter ubique* role in, 303  
 carbon dioxide, 34  
 in Calvin-Benson cycle, 138, 140f  
 capnophiles and, 164  
 catabolic processes and, 134t, 136f  
 chemoaototrophs and, 158, 305  
 crosses plasma membrane by simple diffusion, 91  
 culturing microbes and, 164  
 as fermentation end-product, 132f, 134t  
 “fixed”, 138–139  
 incubators, 164  
 Krebs cycle and, 126f, 127, 138  
 made by yeasts, 134t, 334  
 photoautotrophs and, 158  
 in photosynthesis, 138, 139f  
 photosynthetic bacteria and, 95  
 supercritical, 199, 202t  
 carbon fixation, 115t, 138–139, 140f, 143  
 carbon monoxide, as energy source, 143  
 carbon skeleton, 36  
 carbonate, anaerobic respiration and, 130  
 carboxyl functional group, 36t, 37, 41, 41f, 42t, 43  
 dipicolinic acid and, 48b  
 in fatty acids, 39, 39f  
 carboxysomes, 95  
 carbuncle, 593  
 carcinogens, 230  
 Ames test and, 230–231, 230f, 232b  
 frameshift mutagens as, 227  
*Helicobacter pylori* and, 301t, 313, 314f  
 identifying chemical, 230–231, 230f  
 nitrosamines, 197  
 cardiac muscle, regeneration capacity of, 465  
 cardiotoxins, 438  
 cardiovascular syphilis, 761  
 cardiovascular system, 643–645, 644f  
 lymphatic system in relationship with, 644–645, 645f  
 microbial diseases of, 643–679  
 bacterial, 645–662  
 helminthic, 673–675  
 protozoan, 666–673  
 vector-borne, 655–662  
 viral, 662–666  
 structure/function, 637–638, 638f  
 caribou, lichens and, 342  
 carotene, 345t  
 carotenoids, 144  
 carrageenan, 346  
 carriers of infectious disease, 411  
*Carsonella ruddii*, 327  
 cascade of complement proteins, 467  
 case control method, in analytical epidemiology, 421  
 case reporting  
 CDC’s MMWR and, 422  
 uses in establishing chain of transmission, 422  
 casein, 798  
 caspofungin (Cancidas), 566t, 574  
 catabolic activator protein (CAP), 221–222, 222f  
 catabolic chemical reactions. *See* catabolism  
 catabolism, 32, 112, 112f, 113  
 amphibolic pathways and, 146, 147f  
 carbohydrate, 122–133, 122–133, 136f. *See also* carbohydrate catabolism  
 lipid, 133–135, 135f, 136f  
 protein, 134–135, 136f  
 catabolite repression (glucose effect), 222  
 catalase, 104, 159t, 160  
 hydrogen peroxide and, 104, 199  
 catalysts, 113  
 cataract surgery (Clinical Case), 430b, 436b, 442b, 444b, 446b  
 cathelicidins, produced by neutrophils/macrophages/epithelium, 473  
 catheterization  
 intravenous, 417t  
 urinary, 417t  
 catheters  
 biofilms and, 17, 18f, 161, 433, 586, 587f  
 nosocomial infections and, 161, 417t, 423b  
*Staphylococcus epidermidis* and, 591–592, 592f  
 cationic detergents, as antimicrobial agents, 196, 202t  
 cationic peptides, 578. *See also* antimicrobial peptides  
 cations, 30, 34  
 cats  
 bites, *Pasteurella* and, 312  
*Capnocytophaga canimorsus* and, 484b  
 cat-scratch disease, 305, 413t, 419f, 419t, 653–654, 653f, 655b  
 as disease reservoirs, 413t, 650b  
 feline AIDS and, 379  
 feline leukemia vaccine, 259t  
 feline leukemia virus (FeLV), 393  
 heartworm in, 362, 364t  
 litter box contents flushed, sea otter deaths and, 662  
 plague transmitted by, 657, 658  
 reported cases of rabies in, 630f  
 ringworm and, 605  
 sarcoma viruses in, 393  
*Toxocara cati* and, 360, 364t  
*Toxoplasma gondii* and, 352, 661–662, 662f  
 tularemia pathogen and, 656b  
 vaccinated against leptospirosis, 325  
 cattle  
 anthrax and, 315  
 bovine tuberculosis, 688  
 bovine growth hormone and, 266, 267t  
 reported cases of rabies in, 630f  
*Salmonella* in intestinal tract of, 310  
 sepsis caused by *Pasteurella* bacteria, 312  
 Shiga toxin-producing *E. coli* and, 724  
 tapeworm and, 358–359, 364t  
 ticks, 690  
 cauliflower mosaic virus, 396t  
*Caulobacter* genus/spp., 300t, 304, 305f, 776, 777  
 Caulobacterales, 300t  
 CCR5 (chemokine coreceptors), 545, 553, 571  
 CD (clusters of differentiation) of T cells, 490  
 CD4<sup>+</sup> T cells (T helper cells), 5f, 20, 443, 490–492, 491f  
 in gonorrhea, 749  
 in HIV infection, 20, 545–550, 546f, 548f  
 normal count vs. in AIDS patients, 547, 549  
 CD8<sup>+</sup> T cells (T cytotoxic cells), 490, 493, 494f  
 CD46 measles virus receptor, 443–444  
 CD59 regulatory protein, 470  
 CDC (Centers for Disease Control and Prevention), 422  
 hospital infection control recommendations, 417  
 nosocomial infection estimates by, 415, 416t, 417t  
 priorities for emerging infectious diseases, 418  
 Universal Precautions for Health Care Personnel, 546t  
 cDNA (complementary DNA), 252–253, 254f  
 library, 253  
 CE virus/*Bunyavirus* (California encephalitis), 378t, 626, 626f  
 cefaclor, 565t  
 cefamandole, 565t  
 cefepime, 565t  
 cefixime, 565t, 654t  
 ceftazidime, 565t  
 ceftriaxone, 402b, 423b  
 cell arrangements  
 in algae, 345t  
 in prokaryotes, 75, 76, 77–79, 78f, 79f, 100t, 333t  
 cell-cell fusion of HIV to evade immune system, 547  
 cell counters, 175, 175f  
 cell cultures (viral), 379–380, 380f  
 for vaccine development, 504, 506  
 cell division  
 bacterial growth curves, 170–171, 170f  
 DNA complementary structure and, 208  
 in eukaryotes vs. prokaryotes, 76  
 in prokaryotic vs. eukaryotic cells, 100t  
 cell growth, anabolic reactions and, 112, 112f  
 cell lines (viral), 379–380, 380f  
 cell theory, 6  
 cell-to-cell chemical communication. *See* quorum sensing  
 cell-to-cell interactions  
 glyocalyx’s role in, 99  
 proteins involved in, 90  
 cell walls  
 of algae, 84, 98, 345t  
 of archaea, 87, 100t, 276t  
 atypical, 87–88  
 of bacteria, 40, 69, 84–88, 85f, 100t, 276t, 320, 333t  
 eukaryotic, 76, 84, 98f, 99–100, 100t, 333t  
 of fungi, 38, 84, 333t, 564t, 569  
 Gram stain mechanism and, 86, 87t  
 inserting foreign DNA through, 251–252, 252f  
 pathogenicity and, 433, 447f  
 of plants, 84  
 prokaryotic, 76, 79f, 81, 81f, 84–88, 100t  
 structures internal to, 79f, 88–97  
 synthesis inhibitors (antimicrobial), 561–562, 562f, 564t, 565t, 566t, 567–569, 567f  
 of T-even bacteriophage, 381–383, 382f  
 of yeasts, 99  
 cellular immunity, 480, 489–494, 500f  
 activated macrophages, 490, 490f, 496t  
 antibody-dependent cell-mediated cytotoxicity, 487, 488, 488f, 491, 492f  
 antigen-presenting cells, 489–490  
 congenitally absent thymus gland and, 538  
 cytokines and, 491–492  
 dendritic cells, 494, 494f  
 interleukin-12 activates, 499b  
 intracellular antigens, 486, 500f  
 natural killer (NK) cells, 495  
 principal cells that function in, 496t  
 T cells, 489–494  
 cytotoxic cells, 488–489, 489f  
 helper cells, 487–488, 488f  
 regulatory cells, 489  
 cellular metabolism, rate of, 146  
 cellular oxidations, 120, 120f, 121f  
 cellular respiration (respiration), 122, 123f, 125–130  
 aerobic, 127–130, 130t, 131f  
 Krebs cycle, 122, 125–127, 126f  
 anaerobic, 127  
 glycolysis in, 122, 123f  
 location of, 103  
 overview figure, 123f  
 cellular slime molds, 4, 6, 353–354, 354f  
 cellulases, 3b, 38, 341  
 genetically modified, 246f, 267t  
 cellulitis, MRSA causing, 598b  
 cellulose, 2, 3b, 38, 101  
 algal cell wall, 4, 5, 99, 251–252, 252f, 345t, 346  
*Cytophaga* degrades, 322  
 termites and, 106b  
 Centers for Disease Control and Prevention (CDC), 422  
 hospital infection control recommendations, 417  
 nosocomial infection estimates by, 415, 416t, 417t  
 priorities for emerging infectious diseases, 418  
 Universal Precautions for Health Care Personnel, 546t  
 centimeter (cm), 54t  
 central nervous system (CNS), 616, 616f

- centrifugation, in serum collection, 472b
- centrioles, 98f, 104
- centrosome, 98f, 104–105
- Cepacol (cetylpyridium chloride), 196, 202t
- cephalosporins, 561f, 564t, 569, 721
- cell wall synthesis inhibited by, 561f, 564t, 569
- gram-positive bacteria and, 70
- grouped by generation, 565t
- penicillin allergy history and, 531b
- peptidoglycan and, 100
- structure of, compared to penicillin, 569f
- to treat meningitis, 623t
- to treat staph infection, 2b
- Cephalosporium*, 560, 560t
- cephalothin, 531b, 565t, 569
- produced by *Cephalosporium*, 560, 560t
- Ceratomyx ulmi*, 335f
- Dutch elm disease caused by, 341–342
- cercariae, swimmer's itch in reaction to, 667
- cerebrospinal fluid (CSF), 615, 616, 617f, 621b
- has low levels of defensive cells, 616
- spinal tap (lumbar puncture) and, 619, 620f
- cervical cancers
- HPV vaccine (Gardasil), 259t, 393, 506t, 543, 758
- human papillomavirus (HPV) causing, 387, 393, 396t
- cervical dysplasia, in AIDS patients, 550t
- cervical mucus, antimicrobial activity of, 455
- cervix, 750, 751f
- cestodes, 358–360, 364t. *See also* tapeworms
- cetacean morbillivirus (CM), marine mammal deaths and, 282b
- cetylpyridinium chloride (Cepacol), 196, 202t
- CF. *See* cystic fibrosis
- CF (confocal microscopy), 59–60, 62f, 66t
- Paramecium multimicronucleatum* micrograph, 62f, 66t
- CFS (chronic fatigue syndrome), 638–639
- CFU (colony-forming units), 171
- CGD (chronic granulomatous disease), 466b
- gamma interferon to treat, 473b
- Chagas, Carlos, 10f, 284, 667
- Chagas' disease (American trypanosomiasis), 350, 356t, 364t, 414t, 462, 656b, 666–668, 667f
- as emerging infectious disease, 419t
- Chain, Ernst, 10f, 559
- chain of transmission, case reporting procedure and, 422
- chancere, 760, 760f
- chancroid (soft chancre), 762, 767b
- Haemophilus ducreyi* cause of, 312, 762
- as notifiable infectious disease, 424t
- charge of subatomic particles, 26
- Chatton, Edouard, 273
- cheese
- fermentation and, 134t
- microbes used in making of, 805, 805f
- nisin added to inhibit bacteria, 197
- pH and spoilage, 156
- preservatives added to, 197
- chemical agents
- antimicrobial. *See* antimicrobial agents
- carcinogenic, 230–231, 230f
- genotoxicity and, 230–231, 230f, 232b
- mutagenic, 228
- chemical bonds, 27–31
- covalent, 30, 30f
- high-energy, 119, 120
- ionic, 29–30, 29f
- chemical elements, 26–27, 27t
- chemical energy, 31
- ATP and, 47–48, 48f
- chemical food preservatives, 197, 202t
- chemical messengers, 480
- chemical methods of microbial control, 190–200
- chemical mutagens, 226–227, 226f
- causing frameshift mutations, 227
- chemical pesticides, safety issues, 266–267
- chemical principles, importance to microbiologists, 25
- chemical reactions, 31–33
- anabolic, 112, 112f. *See also* anabolism
- catabolic, 112, 112f. *See also* catabolism
- collision theory and, 113
- coupled, importance of, 112, 120
- energy requirements of, 31, 113, 114f
- enzymes and, 113, 113f. *See also* enzymes
- heat and reaction rate, 113
- reversibility of, 33, 38f
- chemical signals
- alarm signals (alarmons), 221, 223f
- biofilms and, 56b, 161
- chemical spills. *See* bioremediation
- chemical sterilization, 198–199, 202t
- by ethylene oxide, 198, 202t
- by plasma sterilization, 198–199, 202t
- by supercritical fluids, 199, 202t
- chemically defined culture media, 162, 162t, 167t
- chemiosmosis, 121, 123f, 128–130, 128f, 129f, 136f
- chemistry, 25–52, 26
- atoms, 26–27, 27f
- chemical bonds, 27–31
- chemical reactions, 31–33
- elements, 26–27, 27t
- importance to microbiologists, 25
- molecules, 26, 27–31
- chemoautotrophs, 141, 141f, 143, 305
- carbon requirements for growth, 158
- culture media for, 169t
- deep-sea hydrothermal vents and, 157b
- pH ranges and, 156
- chemoheterotrophs, 141, 141f, 143
- carbon requirements for growth, 158
- chemically defined medium for growing, 162t
- culture media for, 169t
- fungi as, 331f, 332
- green sulfur bacteria as, 314t
- helminths as, 331f
- proteobacteria as, 300–301t, 303–313
- chemokine coreceptors, CCR5 and CXCR4, 545
- chemokines, 492
- chemosterilants (gaseous), 199, 202t
- chemotaxis, 82
- as first phase in phagocytosis, 460, 461f
- kinins and, 464
- neutrophils attracted to, 465
- chemotherapeutic drugs. *See also* antibiotics; antimicrobial drugs
- future of, 578–579
- major modes of action (overview), 561f
- salvarsan (antisyphilitic), 12
- spectrum of activity of, 555, 562t
- synthetic drugs, 12
- toxicity to humans and, 11
- chemotherapy, 11, 259t, 558
- history of, 559–560
- selective toxicity and, 553
- tests for microbial susceptibility/sensitivity, 572–573, 572f, 573f
- chemotrophs, 140, 141f
- Chernobyl nuclear disaster, lichens and, 342
- chestnut trees, fungal blight by *Cryphonectria parasitica*, 341
- chick embryos, viruses for vaccines grown in, 379, 379f, 504
- chickenpox (varicella), 377t, 387, 596b, 601–602, 602ff
- breakthrough varicella, 602
- herpesvirus varicella-zoster and, 601
- human herpesvirus 3 and, 601
- incubation period, 431t, 596
- as notifiable infectious disease, 424t
- portal of entry, 431f, 596
- portal of exit, 446
- rash caused by, 596b
- Reye syndrome complication of, 601
- vaccine, 14, 503t, 602
- chickens
- antibiotics in chicken feed, 583b
- cholera in (fowl cholera), 312
- influenza A viruses and, 18
- leukemia in, 392
- sarcoma and, 392
- viral-induced sarcoma in, 392
- chikungunya fever, 656b, 664–665
- childbirth, genetically modified relaxin and, 259t
- childbirth fever (puerperal sepsis), 11, 194, 420, 647, 649b
- childhood immunizations, 505, 507t
- chills and fever, 466
- Chilomastix*, 350f
- chimeric monoclonal antibodies, 514
- as immunosuppressives, 542
- chitin, 4, 38, 100t
- in algal cell walls, 99
- Cytophaga* degrades, 322
- Chlamydia* genus/spp., 302t, 322, 323f
- antimicrobial drugs that inhibit, 562t, 751
- can survive in phagocytes, 462
- classification changes and, 278, 304
- culture media and, 164, 322
- elementary body of, 322, 323f, 372f, 689
- as gram-negative coccoid bacteria, 322
- pathogenic species of, 322
- phylogenetic relationships, 280f
- pneumonia caused by, 322, 695b, 696
- portals of entry, 431, 431t
- taxonomic changes in, 299
- transmission routes, 322
- viruses compared to, 370, 370t
- Chlamydia trachomatis*, 322, 757–758, 767b
- gonorrhea coinfections and, 757
- inclusion conjunctivitis caused by, 609b, 610
- incubation period, 431t
- lymphogranuloma venereum caused by, 322, 462, 762
- as notifiable infectious disease, 424t
- pelvic inflammatory disease caused by, 758
- portals of entry, 431, 431t
- toxin produced by, 261
- trachoma caused by, 322, 609b, 610, 610f
- urethritis (nonspecific) caused by, 431t, 757–758, 767b
- Chlamydiae, 302t, 322
- important genera/special features, 302t
- chlamydial pneumonia, 695b, 696
- chlamydoconidium, 335, 335f, 340t
- Chlamydomonas* (green alga), 345f
- Chlamydomonada* genus/spp., 302t, 322, 323f
- classification changes and, 278
- Chlamydomonada pneumoniae*, 322, 695b, 696
- Chlamydomonada psittaci*, 322, 323f, 680f
- as potential biological weapon, 654b
- psittacosis (ornithosis) caused by, 694–696, 695b
- reservoirs/transmission method, 413t
- Chlor-Floc tablets, to disinfect water, 194
- chloramines, as disinfectants, 194, 202t
- chloramphenicol, 561f, 565t, 570, 570f, 721
- blood-brain barrier and, 611
- produced by *Streptomyces venezuelae*, 560t



- protein synthesis inhibited by, 94, 561f, 565t, 570, 570f  
resistance genes to, 236, 238f  
susceptibility of gram-negative vs. gram-positive bacteria to, 87t  
chlorhexidine, 193, 201t  
chloride ion ( $\text{Cl}^-$ ), in table salt, dissolved in water, 34, 34f  
chloride of lime (calcium hypochlorite), 181, 194  
chlorination  
chlorine dioxide gas and, 194  
of drinking water, 194  
ozone as supplement to, 202, 205t  
chlorine (Cl)  
atomic number/atomic weight, 27t  
as disinfectant, 193–194, 193f, 201t, 202t  
gaseous, to disinfect water, 194, 202t  
as ion, 29, 29f  
peroxide vs., 3b  
chlorine dioxide, 194, 198  
Chlorobi, 302t, 321t, 323  
*Chlorobium* genus/spp., 142, 302t, 321t, 323  
chlorobium vesicles (chlorosomes), 142  
Chloroflexi, 302t, 321t, 323  
*Chloroflexus* genus/spp., 143, 302t, 321t, 323  
chlorophyll a, 138, 143, 143t  
in red algae, 345t  
chlorophyll b, in green algae, 345, 345t  
chlorophyll c, in brown algae, 345t  
chlorophyll d, in red algae, 345t  
chlorophylls, 103, 138, 139f, 143, 143t, 144  
Chlorophyta, characteristics of green algae, 345t  
chloroplasts, 98f, 101, 103–104, 105f, 138, 143t  
of *Euglena*, 351f  
origins of, 274f  
chloroquine, 566t, 577, 585  
chlorosomes (chlorobium vesicles), 143, 143t  
chlortetracycline (Aureomycin), 565t, 570  
produced by produced by  
*Streptomyces aureofaciens*, 560t  
chocolate, fermented before eating, 806  
cholera, 17, 310, 441t, 722–723, 722f, 728b. *See also* *Vibrio cholerae*  
in chickens (fowl cholera), 312, 507  
convalescence and disease spread, 410  
as emerging infectious disease, 419t  
epidemic of 1848 (London) and discovery of source, 420  
exotoxins causing, 439, 441t  
glycoproteins, plasma membranes and, 90  
incubation period, 431t  
modern transportation and spread of, 418  
new strains of, 722  
noncholera vibrios, 723  
as notifiable infectious disease, 424t  
portal of exit, 446  
portals of entry, 431, 431f  
symptoms, 441t  
vaccine, 505–506, 508, 509  
waterborne transmission and, 411  
cholesterol  
structure of, 41, 41f  
synthesis of, 144  
Chromatiales, 301t  
chromatin, 101–102, 102f  
*Chromatium* genus/spp., 301t, 321t, 324, 325f  
as anoxygenic photoautotrophs, 142, 143t  
chromatophores (thylakoids)  
of bacteria, 90, 90f, 138, 143, 143t  
of eukaryotes, 103, 104f, 143t  
chromophore, 67  
chromosomes, 102, 208  
bacterial, 94, 100t, 103  
base sequences and, 209  
DNA and, 79f, 94, 208–209, 209f  
of *Escherichia coli*, 209, 209f  
eukaryotic, 100t, 102  
maps of, 209, 209f  
prokaryotic, 94, 100t, 209, 209f  
chronic disease, 409  
chronic fatigue syndrome (CFS), 638–639  
chronic granulomatous disease (CGD), 466b  
gamma interferon to treat, 473b  
chronic hepatitis B, 730–732  
chronic inflammation/inflammatory response, 463  
chronic viral infections, 394, 394f, 396t  
chronic wasting disease, prion disease  
affecting wild deer/elk, 636  
*Chrysops* (deer fly), as vector  
transmitting tularemia, 363f, 364t, 648, 656b  
chymogen, 267t  
Cidex (glutaraldehyde), 197, 198, 201t, 202t  
cidofovir, 566t, 575  
Ciechanover, Aaron, 13t  
ciguatera, 347, 356t  
cilastatin, 569  
cilia/cilium, 99, 99f  
of eukaryotic cells, 99, 99f  
origins of, 105  
of human respiratory tract, 99, 454  
as defense against pathogens, 454, 474t  
of mucous membranes, 590  
of *Paramecium*, 349f, 353f  
of protozoa, 4, 5, 99, 99f  
of *Tetrahymena*, 99, 99f  
ciliary escalator, 454, 454f, 686  
ciliated cells, 454f  
ciliates, 353, 353f, 356t  
position in evolutionary tree, 274f  
Ciliophora. *See* ciliates  
ciprofloxacin (Cipro), 402b, 565t, 572  
*cis* fatty acid, 39f, 40  
cisternae, 102, 103f, 104f  
citric acid, 125, 126f, 147f  
*Aspergillus niger* fungus used to produce, 341  
biotechnology and, 244  
enteric bacteria and, 284f  
fermentation and, 134t  
citric acid cycle. *See* Krebs cycle  
*Citrobacter* genus/spp., 301t  
as enteric bacteria, 284, 284f  
as normal microbiota of large intestine, 404t  
nosocomial infections and, 416t  
CJD (Creutzfeldt-Jakob disease), 19, 395, 636–637, 636f, 637t, 638b  
clades, 220b, 280  
of HIV, 547  
cladograms, 293–294, 294f  
examples of, 274f, 280f  
clams  
paralytic shellfish poisoning (PSP) and, 344, 356t, 446  
unicellular algae symbionts in giant *Tridacna*, 345  
clarithromycin, 69b, 565t, 571  
bacterial resistance to, 71b  
class switching, 485, 486f  
class (taxonomic), defined, 278, 279f  
classical pathway of complement activation, 467, 468f, 469f  
classification of microorganisms, 6, 272–298  
of eukaryotes, 6, 274f, 280–281  
of infectious diseases caused by, 408–409  
major groups of (overview), 3–6, 5f  
methods, 281, 283–294. *See also* identification of microorganisms  
natural, reflecting phylogenetic relationships, 273, 277  
of prokaryotes, 274f, 278–280, 280f  
study of phylogenetic relationships, 273–277  
hierarchies, 275, 277  
taxonomic hierarchies and, 278, 279f  
three-domain system, 6, 273–277, 274f  
of viruses, 371, 373–374, 377–378t  
*Claviceps purpurea*, 445  
clavulanic acid (potassium clavulanate), 568, 581  
Clear light system, to treat acne, 599–600  
climate, incidence of infectious diseases and, 410  
clindamycin, 570, 599  
*Bacteroides fragilis* resistant to, 238f  
to treat *Clostridium difficile* diarrhea, 565  
clofazimine, to treat leprosy, 626, 632b  
clonal deletion, 485  
clonal expansion of B cells, 485, 486f  
clonal selection of B cells, 485, 486f  
clones/cloning, 245, 280  
applications, 257–266  
agricultural, 263–266, 267t  
scientific, 260–263  
therapeutic, 257–258, 259t  
making a gene product, 156f, 255–257  
of plant cells, 263–266, 266t  
selecting, 255, 255f, 256f  
vectors and, 245, 246f, 248–249, 249f  
cloning vectors, 245, 246f, 248–249, 249f  
*Clonorchis sinensis* (Asian liver fluke), 357, 358f  
Clorox (sodium hypochlorite), 193f, 194  
clostridia. *See* *Clostridium*  
clostridiales, 301t, 314–315, 314f  
*Clostridium acetobutylicum*, fermentation and, 134t  
*Clostridium botulinum*, 314.  
botulism caused by, 616. *See also* botulism  
commercial sterilization to destroy, 182, 794–795, 794f, 795f  
gastric juice unable to destroy, 455  
grows at refrigerator temperatures, 618  
lysogenic phages and, 384  
neurotoxin produced by, 439. *See also* botulinum toxin  
nitrites active against, 197, 202t  
as obligate anaerobe, 159, 314, 616  
as potential biological weapon, 654b  
in soil, 409, 616  
*Clostridium difficile*, 314, 314f, 401f, 404  
antibiotic therapy and, 314, 404, 417b, 441t, 570  
Clinical Case, 402b, 415b, 417b, 418b, 422b  
diarrhea-associated, 314, 402b, 404, 415b, 417b, 418b, 422b, 441t, 720b, 726, 728b  
epidemiological study of outbreak, 418b  
health care-associated/nosocomial, 401, 401f, 416t, 417b  
normal microbiota, antibiotic therapy and, 314, 404  
as nosocomial infection, 417b, 418b, 422b  
resistant to hand sanitizers, 195  
toxin similar to that of *Chlamydia trachomatis*, 261  
*Clostridium* genus/spp., 301t, 314, 314f, 777  
as anaerobic human pathogen, 159, 301t  
canned food spoilage by, 795, 796t  
endospores of, 95–97, 182, 301t, 314, 314f, 800  
fermentation and, 132f  
as gram-variable bacteria, 86  
low G + C content and, 314  
as normal microbiota of vagina, 404t  
*Clostridium perfringens*  
foodborne diarrhea and, 314  
gas gangrene caused by, 314, 431t, 673b  
gastroenteritis caused by, 726, 728t  
incubation period, 431t  
O toxin produced by, 64f, 67t  
portals of entry, 431t  
*Clostridium tetani*, 314, 447f  
incubation period, 431t  
neurotoxin of, 235, 439, 441t, 615  
portals of entry, 431t  
in soil, 409  
tetanus caused by, 314, 406, 621–622, 621f, 638b  
vaccine, 506t, 507t

- clotrimazole, 566t, 574, 606  
club fungi. *See* Basidiomycota  
clue cells, of bacterial vaginosis, 762f, 763  
clumping of cells/viruses, IgM antibodies and, 480, 484  
clusters of differentiation (CD) in T cells, **490**  
cm (centimeter), **54t**  
CM (cetacean morbillivirus) virus, marine mammal deaths and, 282b  
CMV. *See* cytomegalovirus  
CNS (central nervous system), **616**, 616f  
CoA (coenzyme A), **114**, 125, 126f  
coagulase-negative staphylococci, 414, 414t, 591–592, 592f  
coagulase-positive staphylococci, 423b, 423f, 592  
coagulases, **434**, **586**  
virulence factors and, 441–442  
coal mines, 156  
coal tar, phenolics derived from, 192  
Coartem, 671  
cobalamin. *See* vitamin B12  
cobalt, as cofactor, 115  
cocarboxylase, vitamin B<sub>1</sub> and, 115t  
*Coccidioides immitis*, 335, 340t, 703, 703f  
coccidioidomycosis caused by, 418, 703, 706b  
emerging infectious diseases and, 342b, 419t  
increasing rates of infections caused by, 14, 418  
coccidioidomycosis, 339, **703**, **703f**, 704f, **706b**  
airborne transmission and, 412f, 413  
amphotericin B effective against, 568  
as emerging infectious disease, 419t  
epidemic area for, 703, 704f  
incidence increase following natural disaster, 418  
as notifiable infectious disease, 424t  
Valley fever/San Joaquin fever  
synonyms for, 703  
coccobacilli, 77, 77f, 304, 305  
cocci/cocci, 77, 77f  
cocoa  
fermentation used in production of, 806  
*Phytophthora infestans* infects, 347–348  
codeine, as genetically modified product, 257  
codons, 209, **215–218**, 215f, 216–217f  
nonsense (stop), 209, 215f, **216–218**, 216–217f  
sense, **216**  
start, 209, 215f, 216f–217f  
coenocytic hyphae, **332**, 332f  
coenzyme A (CoA), **114**, 115t  
coenzyme Q (ubiquinones), **127**, 127f  
coenzymes, **114**, 114f, 115t  
cofactors of enzymes, **114–115**, 114f, 158  
coffee, fermentation used in production of, 806  
cohort groups/cohort method in analytical epidemiology, 421  
cold-loving microbes (psychrophiles), **154**, 154f  
cold sores (fever blisters), 387, 394, 396t, **603**, 603f, 767b  
herpes simplex virus type 1 (HSV-1) causing, 387, 394, 603, 757  
latent state in nerve cells, 394, 396t, 603f  
cold temperatures, to control microbial growth, 154–156, 154f–156f, 167–168, 188–189, 191t  
cold virus. *See* common cold  
colds. *See* common cold  
*Coronavirus* and, 378t  
*Rhinovirus* and, 377t  
Coley, William B., 542  
Coley's toxins, 542  
coliforms, **786–787**  
counting methods, 172, 174f, 786  
as indicator organisms, **786**, 787f  
colitis  
fatal, 404  
hemorrhagic, 718  
collagen vascular disorders, 470  
collagenase, **435**  
collision theory, **113**  
colony/colonies, 153, **167**  
colony-forming units (CFU), **171**  
*E. coli*, fimbriae's role in forming, 83, 83f  
mutant, replica plating to identify, 229, 229f  
*Proteus* and, 81, 82f, 285f, 311, 311f  
streak plates and, 167, 167f  
colony-forming units (CFU), **171**  
colony hybridization, **255**, 256f  
colony-stimulating factor (CSF), 497  
genetically modified, 257, 259t  
Colorado tick fever, 378t  
colorectal cancer, Clinical Case, 208b, 226b, 231b, 232b  
colorimeter, to measure turbidity, 175, 176f  
colostrum, 498  
gastrointestinal infections and, 484  
IgA's presence in, 484  
comedonal (mild) acne, **599–600**  
commensalism, **405**, 405f, 456  
commercial sterilization, **182**, 183t, 594f, **800–801**  
12D treatment (*botulinal cook*), **800**  
canning retorts, **800**, 801f  
in industrial canning, **800–801**, 801f, 802f  
common cold, **685–686**, **686b**  
adenoviruses causing, 386  
antibody protection against, 480–481  
*Coronavirus* causing, 378t, 685  
portals of entry, 430  
*Rhinovirus* causing, 377t, 685  
transmission of, 685–686  
treatments for, 686  
common variable  
hypogammaglobulinemia, 544t  
communicable diseases, **408**  
control methods, 505  
community-acquired infections, 596, 598–599, 599b, 605b  
community-associated MRSA infections, 21b, 581  
competence (genetic), **233**  
transformation and, 232–233, 233f, 251  
making *Escherichia coli* competent, 251  
competitive exclusion (microbial antagonism), **403–405**  
competitive inhibitors of enzymes, **118**, 118f  
of essential metabolite synthesis, 558, 561f, 562t, 567, 568f  
complement, 466, 479. *See also* complement system  
deficiency of, 467, 472b, 473b  
early discoveries about, 479  
Fc regions of antibodies and, 469f, 482  
testing serum for levels of, 472b  
complement fixation, **512–513**, 514f  
by immunoglobulin class, 483t  
complement-fixation reactions, **517–518**, 519f  
complement fixation tests, 467, 472b  
complement system, **466–470**, **474t**  
activation of, 467, **468f**, 469f  
alternative pathway, **467**, 468f, 470f  
by antibodies, 487, **488**, 488f  
classical pathway, **467**, 468f, 469f  
lectin pathway, **467–468**, 468f, 470f  
in transfusion reactions, 528t, 532–533  
cascading action of, 467  
diseases caused by, 470  
evasion by microbes, 470  
functions of, 466–467  
inherited deficiencies of, 470  
outcomes of activation (overview), **468f**  
protein numbering system, 467  
regulatory proteins of, 469–470  
role in host defenses, 474t  
testing for levels of, 472b  
complementary base pairs, 47, 48f, **208**  
DNA replication and, 210–215, 211f–214f  
sticky ends of DNA strands and, 247–248, 248f  
complementary DNA (cDNA), 252–253, 254f  
complex culture media, **162–163**, 163t, 167t  
complex lipids, **40**, 40f  
complex viruses, **374**, 376f  
composting, **782**  
thermophiles and, 156, 782, 782f  
compound light microscope, 55–57, 55f, 59f, 60f  
magnification and, 58f  
compound microscope, 6, 7f. *See also* compound light microscope  
early versions of, 54–55  
compounds, **27**  
inorganic, **33–36**  
organic, **33**, **36–48**  
compromised hosts, 415f, **416**, 417t  
concentration gradient, 91–93, 91f, 92f  
condensation reaction, 37, 38f  
condenser lens of microscope, 55, 55f, 59f, 60f  
condidiospore (conidium/conidia), 168, **334–335**, 335f, 338, 340t  
*condylomata acuminata*. *See* genital warts  
confocal microscopy (CF), **59–60**, 62f, 66t  
biofilm study improved by, 160  
*Paramecium multimicronucleatum* micrograph, 62f, 66t  
congenital immunodeficiencies, **543**, 544t  
congenital rubella syndrome, **604–605**  
congenital syphilis, **761**  
as notifiable infectious disease, 424t  
congenital toxoplasmosis, 352, 356t  
congestive heart failure, from heartworm disease, 362  
conidia/conidium (condidiospores), 168, **334–335**, 335f, 338, 340t  
condiospores (conidium/conidia), of *Streptomyces*, 319f, 320  
conidium. *See* conidia/conidium (condidiospores)  
conifers, as eukaryon, 6  
*Coniothyrium minitans*, 341  
conjugated proteins, 44  
conjugated vaccines, **508**  
conjugation fungi. *See* Zygomycota  
conjugation in bacteria, 15, **234**, 235f, 236f  
biofilms and, 161  
in *E. coli*, 234, 236f  
as means to map gene location, 209f, 234  
plasmids and, 234, 235–237, 238f  
sex pili and, 84, 234, 235, 235f  
vs. transformation, 234  
conjugation in protozoa, **348–349**, 349f  
conjugation (sex) pili, **84**, 234, 235, 235f  
conjugative plasmids, **235**, 236f  
conjunctiva of eyes  
normal microbiota of, 404t  
as portal of entry, 430, 431t, **447f**, 603  
conjunctivitis, 337, 356t, 431, **609–610**, **609b**  
inclusion, 609b, **610**  
swimming pool, 604  
connective tissue, histamine present in, 464  
constant (C) regions of antibodies, 482, 482f, 483t, 487  
contact dermatitis, allergic, 528t, **535**, 536f, 537b  
lichen causing, 342  
contact inhibition, **444**, 444f  
contact lenses  
biofilms colonizing, 433  
conjunctivitis and, 609–610  
hydrogen peroxide as disinfectant, 202, 610  
contact transmission, **411**, 412f  
contagious diseases, **408**  
*contagium vivum fluidum* (“contagious fluid”), virus first described as, 370  
continuous cell lines, **380**  
control of microbial growth, 181–206  
by altering plasma membrane, 186  
chemical methods, 190–201

- summary (agent/mechanism of action/preferred use), 201–202t  
 microbial characteristics and, 200–201, 200f  
 physical methods, 185–190  
   summary (methods/mechanism of action/preferred use), 191t  
 rate of death and, 183, 183t, 184f  
 terminology of, 182, 183t  
 convalescent home infections. *See* nosocomial infections  
 convalescent period (recovery) stage, **410**  
 copper, 35  
   as an antiseptic, 195–196, 196f, 202t  
   as cofactor, 115  
   copper 8-hydroxyquinoline, 195  
   copper sulfate as algicide, 195–196, 202t  
 cordite, 2  
 core polysaccharide, 85f, **86**  
 corepressors, **221**, 222f  
 corn borer, European, 266  
 corn plants, transposons discovered in, 237  
 cornea  
   *Acanthamoeba* keratitis of, **605**  
   herpetic keratitis of, **605**  
   transplants (Clinical Case), 559b, 570b, 579b, 581b, 584b, 585b  
 coronary artery disease, 16  
   streptokinase to treat blocked, 434b  
 Coronaviridae, **378t**  
 Coronavirus  
   common cold caused by, 378t, 685  
   SARS-associated, 369, 378t, 419t  
 cortex, of lichen, **342**, 343f  
 corticosteroids, to treat psoriasis, 538  
*Corynebacterium diphtheriae*, **319**, 678f  
   diphtheria caused by, 235, 319, 384, 439, 441t, 442t, 684, 684f  
   emerging infectious diseases and, 419t  
   metachromatic granules of, 95  
   phage conversion and, 384  
*Corynebacterium* genus/spp., 302t, 318, **319**  
   G + C content and, 314  
   as normal microbiota of eye, 404t  
   as normal microbiota of mouth, 404t  
   as normal microbiota of skin, 404t, 591  
   as pleomorphic bacteria, 78  
*Corynebacterium xerosis*, as normal microbiota of skin, 591  
 cosmetics and allergic contact dermatitis, 530  
 cotton balls, quat antiseptics neutralized by, 197, 198b  
 cotton plants, insect toxin genetically modified into, 266  
 cotton production, microbes used in, 3b, 38  
 Coulter counters (electronic cell counters), 175  
 counterstains, 68f, **69**, 71  
 coupled chemical reactions. *See under* chemical reactions  
 covalent bonds, **30**, 30f, **31t**  
 cowpox vaccine, 505  
 cowpox virus, 11, 505  
   caused by Poxviridae, 387  
 cows  
   bovine tuberculosis, **688**  
   dairy, bovine growth hormone and milk production, 266, 267t  
   livestock  
     animal feed antibiotics, 554, 562t, 565, 575, 583b  
     bovine growth hormone and, 266, 267t  
     *Pasteurella*-caused sepsis in cattle, 312  
     *Salmonella* in intestinal tract of, 310  
*Coxiella burnetii*, 309  
   endospore-like structures formed by, 96  
   as potential biological weapon, 654b  
   Q fever caused by, 309, 696–697, 696f  
   replicates inside phagolysosomes, 462  
*Coxiella* genus/spp., 301t, 304, **309**  
 coxsackievirus, 377t  
 coyotes, tapeworm *Echinococcus granulosus* in, 359–360, 361f, 364t  
 CPE (cytopathic effect), in cell cultures, **379**, 380f  
 cranberry juice, prevents *E. coli* from adhering to cells, 746  
 crayfish, lung flukes and, 357–358, 359f, 364t  
 Crenarchaeota, 302t, 778  
   gram-negative archaea, 302t  
 cresols, 192, 193f  
 Creutzfeldt-Jakob disease (CJD), 19, 19, 395, **636**–637, 636f, 637t, **638b**  
   variant CJD, compared, 637t  
 crevicular fluid, 714  
 Crick, Frances H. C., 10f, 15, 44, 47  
 crisis phase of fever, **466**  
 cristae/crista, **103**, 104f  
 Crohn's disease, 463  
   interleukin-12 and, 499b  
   monoclonal antibodies to treat, 512  
 crop plants  
   genetic modification and, 263–264, 266–267, 267t  
   MacGregor tomatoes, 267, 267t  
   cross-bridge amino acid, 84, 85f  
   crossing over, **231**–232, 231f  
     in bacteria, 231–232, 231f  
     in eukaryotic cells, 231  
   crown gall disease, 263, 264f, 305  
 Crustacea (class), 363, 364t  
 crustaceans, chitin exoskeleton of, 99  
 crustose lichens, 342, 343f  
 Cruz, Oswaldo, 4t  
*Cryphonectria parasitica*, chestnut tree blight caused by, 341  
*Cryptococcus gattii*, 330, 330f, 332b, 339b, 341b, 342b, **623b**, 632  
*Cryptococcus grubii*, **623b**, 632  
 cryptococcosis, **623b**, **632**–633, 632f  
*Cryptococcus (Filobasidiella)*, 335, 340t, 341  
*Cryptococcus grubii*, 632  
*Cryptococcus neoformans*, **632**–633, 632f  
   in AIDS patients, 550t  
   pathogenic properties, 340t, 445  
 cryptosporidiosis, **19**–20, 737, 737f, **740b**  
   as emerging infectious disease, 19–20, 419t  
   as notifiable infectious disease, 424t  
*Cryptosporidium*, 352–353, 356t, 737, 737f  
   chlorine-resistance and, 357b  
   diarrhea outbreaks and, 19–20, 330, 352–353, 357b  
   emerging infectious diseases and, 19–20, 419t  
   interleukin-12 and, 499b  
   preventing outbreaks, 357b  
   transmission routes, 357b  
*Cryptosporidium hominis*  
   AIDS-associated, 550t  
   diarrhea caused by, nitazoxanide to treat, 571  
   interleukin-12 to treat, 499b  
 crystal violet-iodine (CV-I) complex, 69, 86  
 crystal violet stain, 67, 68, 68f, 71t, 86, 87t  
 CSF (cerebrospinal fluid), 615, 616, 617f, 621b  
   spinal tap (lumbar puncture), 614, 614f  
 CSF (colony-stimulating factor), 497  
   genetically modified, 257, 259t  
 CTL (cytotoxic T lymphocyte), **490**, 493f, 529, 542, 542f  
 cucumbers, lactic acid fermentation and, 134t  
*Culex* (mosquito)  
   as vector for arboviral encephalitis, 364t, 413t, 628b  
   as vector for St. Louis encephalitis, 628b  
*Culiseta* (mosquito), as vector for eastern equine encephalitis, 628b  
 culture media, **161**–166  
   agar, 137f, 158, **162**, 343  
   alternative methods to, 406  
   for anaerobic microbes, 163, 164f  
   bacterial growth in, 168–177  
     bacterial division, 168, 168f  
     cell division and, 153, 168–169, 169f  
     direct measurements, 171–175  
     estimating numbers, 175–177  
     generation time, 168–169, 169f  
     logarithmic representations, 169–171  
     phases of growth, 170–171  
   chemically defined, **162**, 162t, 167t  
   complex, **162**, 163t, 167t  
   differential, 137, 137f, **165**–166, 165f, 166f, 167t  
   enrichment, **165**–166, 167t  
   filtration and, 188  
   for growing bacteriophages, 376, 376f  
   *Haemophilus* bacteria special requirements and, 312  
   nutrient broth/nutrient agar for, **163**, 163t  
   reducing media, **163**, 167t  
   salt concentration and, 158  
   selective, **165**, 167t, 284, 285  
   solidifying agents, 165. *See also* agar  
   special techniques, 163–165, 164f, 165f  
   sterilization of, 162, 188  
   summary, by type/purpose, 167t  
   trace elements and, 158  
   transport, **283**  
   viruses and, 164, 376, 377–380  
 culture plates/petri plates, 162  
 cultures, **162**  
   bacterial growth in, 168–177. *See also under* culture media  
*Cupriavidus*, 143  
 curd, in cheese production, 805, 805f  
 cutaneous anthrax, **651**, 651f, 655b  
   virulence of, 432  
 cutaneous diphtheria, **684**  
 cutaneous mycoses (dermatomycoses), **340**, 340t, **605**–607, 606f  
   ketoconazole to treat, 568  
 cuticles  
   of flukes, **356**  
   of tapeworms, 358  
 CV-I (crystal violet-iodine) complex, 69, 86  
 CXCR4 (chemokine coreceptors), 545  
 cyanide, 118  
   as an enzyme poison, 118  
 cyanobacteria, 302t, **320**–322, 321f, 321t  
   alkaline habitats and, 35  
   environmental role of, 321  
   evolutionary contributions of, 321  
   fossil evidence and, 277, 321  
   gas vacuoles and, 95, 321  
   habitat and, 341f  
   important genera/special features, 302t  
   lichens and, 342  
   as nitrogen fixers, 15, 158, 321  
   pH ranges and, 35  
   as photoautotrophs, 141–143, 141f, 302t  
   photosynthesis and, 138, 141–143, 141f, 143t, 158, 320–322, 321t  
   phylogenetic relationships, 280f, 320  
   position in evolutionary tree, 274f  
   selected characteristics, compared, 321t  
 cyanocobalamin (vitamin B<sub>12</sub>), 115t  
*Cyanophora paradoxa*, 275f  
 cyclic AMP (cAMP), **221**–222, 222f, 223f  
 cyclic photophosphorylation, **138**, 139f  
 cyclic side group of amino acids, 41, 41f, 42t  
*Cyclospora cayatanensis*, 353, 356t, 419t, 737–738, 740b  
*Cyclospora* diarrheal infection, 356t, 737–738, **740b**  
 cyclosporine, 541–542, 554b  
 cysteine (cys)  
   disulfide bridges of, 44, 45f  
   structural formula/characteristic R group, 42t  
 cystic acne, 455



- cystic fibrosis (CF), 16  
 biofilm-forming *P.aeruginosa* in, 56b, 161  
 biofilms and, 56b, 161  
*Burkholderia* infections and, 306, 309  
 DNA sequencing and, 261, 261f  
 genetically modified enzyme used to treat, 259t  
*Pseudomonas* infections and, 56b, 308, 309, 570  
 tobramycin to treat, 570  
 cysticerci, 358  
 cysticercosis, 358, 739  
 cystitis, 752, 753b  
 cysts of protozoa, 331f, 349, 351, 352  
 of *Chilomastix*, 350f  
 chlorine dioxide activity against, 194  
 of cryptosporidiosis, 737  
 of *Giardia*, 349, 350f, 736–737  
 resistance to chemical biocides, 200, 200f  
 cyt (cytochromes), 129–130, 129f  
 cytochrome c oxidase, 137  
 cytochrome oxidase, 115t  
 cytochromes (cyt), 127–128, 127f  
 cytotoxic effects of viruses, vs. noncytotoxic effects, 443  
 cytokine storm, 497, 527  
 of 1918 influenza pandemic, 694  
 cytokines, 439, 440f, 452, 464, 495–497, 500f  
 in B cell activation, 484, 484f  
 in cellular immunity, 496–497, 500f  
 as chemical messengers, 496  
 chemokines, 496  
 fever and, 466  
 hematopoietic, 497  
 in humoral immunity, 469, 484f, 485, 496, 500f  
 inflammatory response and, 464, 464f, 465  
 interferons as, 471, 496  
 interleukin-1 (IL-1), 440, 466  
 interleukin-12 (IL-12) as “magic bullet”, 499b  
 overproduction (cytokine storm), 497  
 phagocytosis and, 460  
 symptoms induced by, 439  
 T cell secretion of, 480  
 as therapeutic agents, 492, 499b  
 in tissue repair, 465  
 toxic at high concentrations, 440  
 tumor necrosis factor and, 440, 440f, 496–497  
 cytotoxicity, 457t, 458  
 by complement activation, 467, 469f  
 cytomegalovirus (CMV), 649b, 664  
 AIDS-associated, 549, 550t, 664  
 cytomegalic inclusion disease (CID), 664  
 cytopathic effects of, 445t  
 eye infections, 542, 575, 664  
 inclusion bodies of, 387, 664  
 pregnancy and, 664  
 U.S. prevalence of antibodies against, 663f  
*Cytomegalovirus* (HHV-5), 377t, 649b  
 cytomegalovirus retinitis, 542, 575, 664  
 cytopathic effects (CPE)  
 in cell cultures, 379, 380f  
 of viruses, 443–444, 444f, 445t  
*Cytophaga* genus/spp., 302t, 322, 777  
 cytoplasm  
 eukaryotic cell, 98f, 100–101, 100t  
 prokaryotic cell, 79f, 94, 100t  
 cytoplasmic membrane. *See* plasma membrane  
 cytoplasmic streaming, 100t, 101, 354, 355f  
 cytosine (C), 46f, 47, 48f, 208  
 in DNA replication, 210–215, 211f–214f  
 in translation, 216, 216–217f, 218f  
 cytoskeleton, 100t, 101, 435  
 cytosol, 101  
 cytostome, 349  
 of ciliates, 353f  
 of euglenoids, 349, 351f  
 cytotoxic reactions (Type II hypersensitivity), 528t, 532–534  
 drug-induced reactions, 533–534, 534f  
 transfusion reactions, 532–533, 532t, 533f  
 cytotoxic T lymphocyte (CTL), 490, 493f, 496t, 542, 542f  
 cytotoxins, 438  
**D**  
 D-amino acids, 41, 43f, 84, 85f  
 D-glucose, 41  
 D value/DRT (decimal reduction time), 185  
 dairies, disinfectants used in, 194  
 dairy cows, bovine growth hormone and milk production, 266, 267t  
 dairy equipment, chloramines to sanitize, 194, 201t  
 dairy products  
 butter/buttermilk, 806  
 cheese. *See* cheese  
 cultured sour cream, 806  
 estimating bacterial populations in, 173, 175f  
 genetically modified rennin and, 267t  
*Listeria* and, 317  
*Listeria monocytogenes* and, 317  
 microbes used in producing, 317, 806  
 pasteurization of, 187–188  
 phosphatase test and, 187  
 streptococci important to production of, 317  
 yogurt, 806  
 dalfopristin, 565t, 571  
 dandruff, 591  
 dapsone, to treat leprosy, 626, 632b  
 daptomycin, 565t, 572  
 darkfield microscopy, 57, 60f, 66t  
 Darwin, Charles, 272  
 daughter cells  
 in DNA replication, 210–215, 211f–214f, 224f  
 in flow of genetic information, 209, 210f  
 mutation and, 224f  
 DDT, 16, 17, 781  
 deamination, 135, 776–777, 776f  
 death (human), fever and, 466  
 death (microbial)  
 exponential rates of, with antimicrobial treatments, 183, 183t  
 logarithmic decline phase of bacterial growth and, 170f, 171  
 microbial death curve (Foundation Figure), 184f  
 deathcap mushroom (*Amanita phalloides*), 445  
 debridement, 622  
 decarboxylation, 125, 126, 126f, 135, 136, 137f  
 biochemical test for, 136, 137f  
 decimal reduction time (DRT/D value), 185  
 decimeter (dm), 54t  
 decolorizing agents, 68, 68f  
 decomposers  
 fungi as, 332  
 oomycetes as, 347, 347f  
 water molds as, 344  
 decomposition reactions, 32  
 deep, in relation to culture dishes, 162  
 deep-freezing  
 to control microbial growth, 194t  
 to preserve bacterial cultures, 168  
 deep-sea hydrothermal vents, 156, 157b  
 deer  
 chronic wasting disease (prion-caused), 636  
 as disease reservoirs, 360, 361f, 413t, 656b  
 deer fly (*Chrysops*), as vector for tularemia, 363f, 364t, 648, 656b  
 deer fly fever, 642  
 deer fly/rabbit fever. *See* tularemia  
 deer mice, as disease reservoirs, 413t  
 defecation, 455, 474t  
 defenses of human body. *See* immunity  
 defensins, 473, 579, 589, 713  
 defensive cells of innate immunity, 474t  
 natural killer (NK) cells, 457t, 458, 474t, 495, 496t  
 phagocytes, 452f, 457t, 460–463, 474t  
 definitive host, 351, 364t  
 of *Echinococcus granulosus*, 359–360, 361f, 364t  
 of *Plasmodium vivax*, 351–352, 352f  
 of selected parasitic helminths, 364t  
 of *Taenia saginata*, 358, 364t  
 of *Taenia solium*, 359, 364t  
 degeneracy of genetic code, 216, 224, 254  
 degenerative evolution, 318  
 degerming/degermination, 182, 183t, 196, 202t  
 alcohol swabs as, 194, 202t  
 soaps as, 196, 196f, 202t  
 degradation of synthetic chemicals  
 bioremediation, 775, 776f  
 composting, 782  
 solid municipal waste, 781–782  
 degradative chemical reactions. *See* catabolism  
 degranulation, 529, 529f  
 dehydration, fever and, 466  
 dehydration synthesis, 37, 38f, 43, 44f, 112  
 dehydrogenase enzymes, 114, 115t  
 dehydrogenation, 120, 121f, 135.  
*See also* redox reaction  
 biochemical test for, 136, 137f  
 deinococci, 326  
*Deinococcus* genus/spp., 302t, 326  
*Deinococcus radiodurans*, 326  
*Deinococcus-Thermus*, 302t  
 delayed (Type IV) hypersensitivity reactions, 528, 528t, 535, 536f, 537b  
 Delbrück, Max, 10f  
 delirium, fever and, 466  
 delta hepatitis. *See* hepatitis D  
 deltaproteobacteria, 301t, 303, 312–313  
 Deltaviridae, 378t  
 denaturation of proteins, 44, 117, 117f  
 by heat treatments, 185–188, 186f, 191t  
 dendritic cells (DCs), 457t, 458, 490, 494, 494b, 494f  
 as antigen-presenting cells, 494, 494f  
 antimicrobial proteins (AMPs) and, 473  
 in second line of defense, 452, 452f  
 dengue fever, 377t, 419t, 643, 667, 667b  
*Aedes* mosquito as vector, 364t, 414t  
 Clinical Case, 644b, 662b, 665b, 668b, 675b  
 as emerging infectious disease, 419t  
 as nationally notifiable infectious disease, 424t  
 dengue hemorrhagic fever (DHF), 364t, 643f, 667, 667b  
 as emerging infectious disease, 419t  
 denim blue jeans, made by microbes, 3b  
 denitrification, 776f, 777  
 dental caries (tooth decay), 713–715, 714f, 716b  
*Bacteroides* and, 322  
*Fusobacterium* and, 322, 324f  
*Streptococcus mutans* and, 80, 135b, 137b, 317, 432, 441, 713–715, 714f  
 dental plaque, 111f, 713  
 as biofilm, 80, 161, 432, 713  
 dextran, *Actinomyces*, *Streptococcus mutans* and, 431, 441  
 dental work, medical implants, biofilms and, 537b  
 deoxynucleotides (dNTPs), 250f  
 deoxyribonucleases, 595  
 deoxyribonucleic acid. *See* DNA  
 deoxyribose, 37, 46f, 47, 208  
 in DNA replication, 211f–214f  
*Dermacentor andersoni* (wood tick)  
 Rocky Mountain spotted fever transmitted by, 364t, 661  
 as vector of *Rickettsia rickettsii*, 413t  
*Dermacentor* spp., 364t  
*Dermacentor variabilis* (dog tick), Rocky Mountain spotted fever transmitted by, 661  
 dermatitis, *Pseudomonas*, 591, 593–594

- dermatomycoses (cutaneous mycoses), **340**, **340t**, **605–607**, **606f**  
ketonazole to treat, **568**  
dermatophytes, **340**, **605**  
dermatomycoses (cutaneous mycoses) caused by, **340**, **340t**  
keratinase enzyme secreted by, **340**, **600**  
dermicidin, **473**  
dermis, **453**, **453f**, **590**, **590f**  
descriptive epidemiology, **420–421**  
desensitization to antigens, **531**  
to penicillin allergy, **530**  
desiccation, **189**, **191t**  
designer jeans, made by microbes, **3b**  
*Desulfovibrio* genus/spp., **301t**, **312**, **777**  
anaerobic respiration and, **130**  
as sulfate reducers, **301t**  
Desulfovibrionales, **301t**, **312**  
Desulfurococcales, **302t**  
detergent (SDS), **256f**  
detergents and soap, **196**, **196f**, **202t**  
acid-anionic sanitizers, **196**  
cationic, **196–197**, **202t**  
gram-negative bacteria and, **86**, **87t**  
*Deuteromycota*, **338**  
developing countries, parasitic diseases and, **330**  
devescovinids, **106b**  
dextran, **38**, **713**  
*Actinomyces*, *Streptococcus mutans* and dental plaque, **432**, **441**, **713–714**  
dextransucrase, produced by *Streptococcus mutans*, **441**  
DHAP (dihydroxyacetone phosphate), **122**, **124f**  
diabetes mellitus, **538**  
gene therapy and, **16**  
insulin produced by rDNA technology, **2**, **245**, **254**, **257**, **259t**  
mucormycosis and, **341**  
diagnostic immunology, **511–523**. *See also* diagnostic tests  
diagnostic tests  
agglutination reactions, **510–512**, **510f**, **511f**  
complement-fixation reactions, **512–513**, **514f**  
DNA probes and, **517**. *See also* DNA probes  
ELISA test, **286**, **286f**, **519–521**, **523f**  
enzyme-linked immunosorbent assay (ELISA), **519–521**, **523f**  
fluorescent-antibody (FA) tests, **513–514**, **515f**  
for HIV detection, **545**  
monoclonal antibodies, **512–514**, **513f**  
neutralization reactions, **512**, **513f**  
precipitation reactions, **514–515**, **514f**, **515f**  
rDNA technology and, **261**  
sensitivity and, **512**  
specificity and, **512**  
for viral RNA, **545**  
Western blotting, **286–287**, **288f**, **380**, **510**, **521**  
dialysis patients, at risk for gram-positive sepsis, **640**  
diapedesis, **464f**, **465**  
diarrhea, **356t**, **717**  
antibiotic-associated, **441t**  
cholera and, **310**, **439**, **441t**  
Clinical Case, **402b**, **415b**, **417b**, **418b**, **422b**  
*Clostridium difficile*-associated, **415b**, **417b**, **418b**, **422b**, **441t**, **720**, **720b**  
cryptosporidiosis and, **19–20**, **356t**  
*Cryptosporidium* causing, **356t**  
*Cyclospora cayetanensis* causing, **356t**, **419t**  
*Escherichia coli* O157:H7 and, **19**, **83**, **419t**  
hemorrhagic, **419t**  
infant, **235**  
infant mortality and, **717**  
microsporidia causing, **337**, **337f**, **340t**  
nosocomial/health-care-associated, **415b**, **416t**, **417b**, **418b**, **422b**  
persistent, in HIV/AIDS patients, **549**, **550t**  
traveler's, **235**, **310**, **441t**, **724**  
waterborne (recreational), **352–353**, **357b**  
diarylquinoline, experimental anti-TB drug, **684**  
diatoms, **345t**, **346**, **346f**  
neurologic disease outbreak from ingesting, **346**  
DIC (differential interference contrast) microscopy, **59**, **61f**, **65t**  
DIC (disseminated intravascular coagulation), **440**  
Dicer (enzyme), **258**  
dichotomous keys, **293**  
examples of, **282b**, **284**, **303**  
*Dictyostelium*, **354f**  
differential culture media, **137**, **137f**, **165–166**, **165f**, **166f**, **167t**  
to identify pathogenic *Escherichia coli*, **136**, **137f**, **162t**, **165**  
differential interference contrast (DIC) microscopy, **59**, **61f**, **65t**  
differential stains, **68–69**, **68f**, **70f**, **71t**, **284**  
differential white blood cell count, **457t**, **458**  
Differin (adapalene), **599**  
diffraction of light rays, **60**, **60f**  
diffusion  
chemiosmosis and, **128**, **128f**, **129f**  
facilitated, **91–92**, **91f**  
simple, **91**, **91f**  
diffusion methods (to evaluate antibiotic sensitivity)  
disk-diffusion method, **195**, **196f**, **572**, **572f**  
E test, **572**, **573f**  
DiGeorge's syndrome, **541b**, **543**, **544t**  
digestion phase of phagocytosis, **461f**, **462**  
digestive enzymes, lysosomes and, **103**  
digestive system, **711–748**  
fecal-oral cycle and, **711**  
immune system's interrelationship with, **712**  
infections in, vs. intoxication, **716**  
microbial diseases  
bacterial, **713–727**, **728b**  
fungal, **735–736**, **740b**  
helminthic, **738–744**, **740b**  
protozoan, **736–738**, **740b**  
viral, **390**, **727–735**, **736b**  
normal microbiota of, **712–713**  
ruminant, microbes in biofilms and, **161**  
structure/function, **712**, **712f**  
digestive system infections, Reoviridae and, **390**  
dihydroxyacetone phosphate  
in biosynthesis of lipids, **147f**  
in lipid catabolism, **135f**  
dihydroxyacetone phosphate (DHAP), **122**, **124f**  
diiodohydroxyquin (iodoquinol), **577**  
dilation, of blood vessels (vasodilation), **464**, **464f**  
diiodohydroxyquin, mode of action/uses, **564t**  
dilution tests of antibiotics, **572–573**, **573f**  
dimers  
secretory IgA and, **484**  
unrepaired, and skin cancers, **228**  
dimethicone, **608**  
dimorphic fungi, **334**, **334f**, **340t**  
dimorphism, **334**, **334f**  
sexual, **360**  
Dinoflagellata, **345t**, **356t**  
dinoflagellates (plankton), **345t**, **346–347**, **346f**, **356t**  
blooms and polluted water, **348**  
photosynthesis of, and Earth's oxygen supply, **348**  
planktonic bacteria, biofilms and, **161**, **161f**  
dioecious helminths, **356**  
dipeptide, **43**, **44f**  
diphosphoglyceric acid, **140f**  
diphtheria, **17**, **95**, **235**, **441t**, **684–685**, **684f**, **686b**  
1990's epidemic, adult vaccination booster and, **418**  
*Corynebacterium diphtheriae* causing, **319**, **384**, **441t**, **684**, **684f**  
cutaneous diphtheria, **684**  
as emerging infectious disease, **419t**  
membrane in throat characteristic of, **684**, **684f**  
as notifiable infectious disease, **424t**  
symptoms of, **407**, **441t**, **684**  
toxin causing. *See* diphtheria toxin vaccine, **506t**, **507t**, **684**  
diphtheria toxin, **438**, **438f**, **439**, **441t**, **442**  
mechanism of action, **438f**  
produced by *Corynebacterium diphtheriae*, **235**, **438f**, **439**, **441t**  
vaccine produced from purified toxoid, **506t**, **508**  
diphtheroids  
as normal microbiota of eye, **404t**  
as normal microbiota of nose, **404t**  
as normal microbiota of skin, **591**  
as normal microbiota of urethra, **404t**  
*Diphyllobothrium latum* fish tapeworm, **739**  
dipicolinic acid (DPA), **44b**, **48b**, **97**  
diplobacilli, **77**, **77f**  
diplococci, **77**, **77f**  
diploid cell lines, **379–380**  
Diplomonads, **356t**  
direct agglutination tests, **515–516**, **516f**  
direct contact transmission, **411**, **412f**, **413t**  
in nosocomial infections, **414–417**  
direct ELISA tests, **514**, **520–521**, **523f**  
direct FA tests, **518**, **520f**  
direct flaming sterilization, **188**, **191t**  
direct microscopic count of bacteria, **173**, **175**, **175f**  
direct (positive) selection method to identify mutations, **229**  
*Dirofilaria immitis*, **361–362**, **362f**  
*Wolbachia* bacteria essential to, **362**  
disaccharides, **38**, **38f**, **86**  
disease principles, **401–428**  
acute disease and, **409**  
chronic disease and, **409**  
classification and, **408–409**  
Clinical Case, **402b**, **415b**, **417b**, **418b**, **422b**  
communicable disease and, **409**  
contagious disease and, **409**  
cooperation among microbes and, **406**  
degenerative, vs. infectious disease, **406**  
diagnosis of, **408**  
antibody presence (IgM) and, **480**  
duration or severity of, **409**  
endemic disease and, **408**  
epidemic disease and, **408**  
etiology determination and, **406–408**, **407f**  
germ theory of, **8–9**, **11**, **406–408**, **407f**, **477**  
health care-associated infections and, **414–417**. *See also* nosocomial infections  
incidence and, **406**  
infection, vs. disease, **402**  
infectious disease and, **17**, **406–410**. *See also* infectious diseases  
inherited (genetic), vs. infectious disease and, **406**  
noncommunicable disease and, **408**  
normal microbiota/microbiota and, **402–405**, **403f**, **404t**  
occurrence of disease and, **408–409**, **408f**  
pandemic disease and, **409**  
pathogenesis and, **402**  
pathology as study of, **402**  
patterns of, **409–410**  
predisposing factors, **410**  
prevalence, **406**  
self-limiting, **676**  
severity or duration of, **409**  
signs and symptoms, **406**  
sporadic disease and, **408**  
spread of infection, **411–414**, **446**  
stages of disease development, **410**, **410f**  
syndromes, **406**

- transmission routes and, 411–414.  
*See also* transmission of disease  
 vaccinations and, 505–511  
 vs. infection, **402**
- disease reservoirs, **411**  
 animal and human, 411, 413*t*  
 nonliving (soil/water), 411  
 of zoonoses/with transmission  
 methods, 413*t*
- disinfectants  
 alcohols, 194–195, 194*t*, 201*t*, 202*t*  
 aldehydes, **197**, 202*t*  
 antibiotics as, 197  
 bacteria that can grow in, 196*f*, 202  
 bacterial plasma membrane  
   damaged by, 90  
 biguanides, 193, 201*t*  
 bisphenols, 192–193, 193*f*, 201*t*  
 Cepacol, 196, 202*t*  
 chemical food preservatives,  
   197, 202*t*  
 chemical sterilization, 198–199,  
   202*t*  
 chlorhexidine, 193, 201*t*  
 chlorine, 193–194, 193*f*, 202*t*  
 choosing effective, 192  
 copper, 195–196, 195*f*  
 detergents, 196, 196–197, 196*f*, 202*t*  
 disk-diffusion method to evaluate,  
   192, 193*f*  
 early uses of, 9, 11  
 evaluating effectiveness of, 192, 193*f*  
 formaldehyde, 197  
 glutaraldehyde, 197, 201*t*, 202*t*  
 halogens, 193–194, 202*t*  
 heavy metals, 195–196, 195*f*, 202*t*  
 hexachlorophene, 192, 193*f*  
 hydrogen peroxide, 202  
 iodine, 193–194, 201*t*, 202*t*  
 mercury, 195, 202*t*  
 nitrates/nitrites, 197, 202*t*  
 peroxygens, 202  
 phenol, 11, 192, 193*f*, 201*t*  
 phenolics, 192, 193*f*, 201*t*  
 plasma sterilization, 201  
 quats, 90, 193*f*, 196–197, 196*f*, 200,  
   201*t*, 202*t*  
 silver, 195–196, 195*f*  
 silver-sulfadiazine, 195, 202*t*  
 soaps, 196, 196*f*, 202*t*  
 sulfur dioxide, 197  
 supercritical fluids, 199, 202*t*  
 surface-active agents/surfactants,  
   192, 193*f*, 196–197, 196*f*, 201*f*,  
   202*t*  
 Surfactine, 195  
 temperature and effectiveness of,  
   183  
 triclosan, 192–193, 193*f*, 201*t*, 566  
 types of, 192–199  
 use-dilution tests to evaluate, 192  
 vs. antiseptics, 182  
 zinc, 195
- disinfection, **182**, 183*t*. *See also*  
 disinfectants  
   evaluating effectiveness of, 192, 193*f*  
   principles of, 192  
   water treatment, 782*f*, 788, 789*f*  
 disinfection and release in sewage  
   treatment, 790*f*, **792**  
 disk-diffusion assays/tests, **192**, 193*f*  
 to evaluate antibiotic sensitivity  
   (Kirby-Bauer test), **578**, 578*f*  
 to evaluate disinfectants, 192, 193*f*,  
   198*b*
- disseminated intravascular coagulation  
 (DIC), 440, 479*b*
- dissimilation, **779**, 780*f*
- dissimilation plasmids, **235**
- dissimilatory metabolism, 312
- dissociation (ionization), **34**, 34*f*
- distilled water, microbial growth and,  
 158
- disulfide bridges, 44, 45*f*  
 of antibodies, 479, 480*f*  
 antimicrobial agents and, 184
- diversity  
 genetic, 231, 239  
 microbial, 327–328, 767
- dm (decimeter), **54*t***
- DNA, **37**, **44**, 46*f*, **47**  
 amplification of, 245  
 antimicrobial agents and, 184  
 of bacterial cells, 79*f*, 94  
 base pairs, **208**  
 in binary fission, 168*f*  
*bullets* via gene guns, 251–252,  
   252*f*  
 complementary (cDNA), 252–**253**,  
   254*f*  
 complementary strands, **208**  
 conjugation, 15, 84  
 DNA bar code proposed, 290  
 double helix, 46*f*, **47**, 58*f*, 208  
 enzymes of replication process,  
   210–215, 211*t*  
 in eukaryotic cells, 101–102, 276*t*  
 extraction from mummies/extinct  
   plants/animals, 263  
 location in eukaryotic cells, 101  
 mitochondrial, 103  
 mutagenic agents and, 226–231  
 mutation and, 223–231. *See also*  
   mutations  
 “naked,” transformation process  
   and, 232, 251  
 probes, **255**, 256*f*  
 in prokaryotic cells, 79*f*, 276*t*, 945  
 protein involved in repair of, 64*f*  
 protein synthesis and, 146  
 radiation damage to, 189–190, 191*t*  
 recombinant, **15**  
 replication, 210–215. *See also* DNA  
   replication  
 RNA compared to, 48*t*  
 STM microscopes to view, 64, 64*f*  
 structure of, 46*f*, 47, 208–209, 209*f*,  
   211*f*–212*f*, 212–213  
 sugar-phosphate backbone of, **208**,  
   214*f*, 215*t*, 248, 248*f*  
 supercoiled strands of, 209, 209*f*  
 synthesis of from nucleotides, 146  
 synthetic, **253**–254, 254*f*  
 transcription and, 210*f*, 214*f*, **215**  
 transfer, pili and, 83–84  
 UV light damage to, 190, 191*t*  
 vaccines, **503**–504  
 of viruses, 5, 370, 371
- DNA base composition test, **289**
- DNA chips (microarray/PCR  
 microarray), 261, **292**, 292*f*,  
 521–522
- DNA-DNA hybridization reaction,  
 290, 291*f*, 292  
 in classification of microbes, 278  
 evolutionary relationships and, 277
- DNA fingerprinting, 209, **261**, 263,  
 263*f*, **289**–290, 289*f*, 293*b*, 294*b*
- DNA gyrase, 211*t*
- DNA ligase, 111*t*, 212*f*  
 in making recombinant DNA, 248,  
 248*f*
- DNA oncogenic viruses, 393
- DNA polymerase, **210**, 211*t*, 212*f*  
 deep-sea hydrothermal vent bacteria  
   and, 157*b*  
 in PCR process, 249–251, 250*f*, 552*f*  
 proofreading ability of, 214–215
- DNA probes, **255**, 256*f*, **290**, 291*f*,  
 292, 521  
 by colony hybridization, **255**, 256*f*  
 DNA chip technology and, **292**,  
   292*f*  
 in Southern blotting, 261, 262*f*, **290**,  
   291*f*, 292
- DNA recombination, 210*f*  
 enzymes important in, 210, 211*t*
- DNA repair  
 by excision repair, 227–228, 228*f*  
 important enzymes in, 210, 211*t*,  
   227  
 by light-repair enzymes, 227  
 radiation causing errors in, 227  
 RecA protein and, 64*f*, 231*f*, 233
- DNA replication, 210–215, 211*f*–215*f*  
 direction of DNA strands and, 211*f*,  
   212–213, 213*f*  
 in DNA viruses, 385*t*, 386–388, 387*f*,  
   388*f*, 388*t*  
 in *E. coli*, 213–214, 213*f*  
 energy supply for, 212*f*, 213  
 enzymes important in, 210, 211*t*  
 flow of genetic information and,  
   209, 210*f*  
 mistakes in, 214–215, 226–231  
 rates for spontaneous errors, 231  
 nucleoside analogs and, 226–227,  
   227*f*  
 radiation causing errors in, 227  
 replication fork, 210, 211*f*–213*f*  
 in *Escherichia coli* bacteria,  
   213, 213*f*  
 events at (summary), 212*f*  
 semiconservative, **212**  
 transcription and, 210*f*, 214*f*, 215  
 translation and, 210*f*, **215**–218,  
   216–217*f*, 218*f*
- DNA reverse transcriptase viruses,  
 388*t*
- DNA sequencing  
 bioinformatics and, **261**  
 in cystic fibrosis research, 261, 261*f*  
 fungi placed closer to animals than  
   plants, 273  
 reverse genetics and, 261  
 shotgun sequencing and, 260, 260*f*
- DNA strands  
 blunt ends, **247**, 248*f*  
 sticky ends, 215*t*, 238*f*, **247**–248,  
   248*f*
- DNA synthesis  
 antibiotics that inhibit, 567  
 nitrogen requirements, 158
- from nucleosides with deoxyribose,  
 214
- DNA technology  
 agricultural applications, 263–264,  
   264*f*, 266, 267*t*  
 genome projects, 260, 261  
 recombinant, **15**, **245**. *See also*  
   recombinant DNA (rDNA)  
   technology  
   scientific applications, 260–263  
   therapeutic applications, 257–258,  
   259*t*
- DNA vaccines, **258**, **508**
- DNA vectors (gene-cloning vectors/  
 cloning vectors), 245, 246*f*,  
 248–249, 249*f*
- DNA viruses, 377*t*, 385*t*, **386**–388,  
 387*f*, 388*f*, 388*t*, 392*b*
- dogs  
 bites, *Pasteurella multocida* and,  
   312, **653**  
 canine distemper vaccine, 259*t*  
*Capnocytophaga canimorsus* and,  
   479*b*, 480*b*, 484*b*, 487, 490*b*,  
   494*b*  
 as disease reservoirs, 413*t*  
 heartworm in, 361–362, 362*f*  
 raccoon roundworm and, 360  
 reported cases of rabies in, 630*f*  
 ringworm and, 605  
 tapeworm *Echinococcus granulosus*  
   in, 359–360, 361*f*, 364*t*  
*Toxocara canis* and, 360, 364*t*  
 vaccinated against leptospirosis, 325
- Doherty, Peter C., 13*t*
- dolphins, bottlenose, 282*b*, 282*f*
- Domain Archaea, 75, 76, **274**–275,  
 274*f*, 276*t*, 300, 302*t*, **326**, 326*f*  
 members of, 274–275, 274*f*  
 position in evolutionary tree, 274*f*  
 position in taxonomic hierarchy,  
   279*f*
- Domain Bacteria, **274**, 274*f*, 276*t*,  
**303**–326. *See also* bacteria;  
 prokaryotes  
 gram-positive bacteria of, 314–320.  
   *See also* gram-positive bacteria  
 nonproteobacteria gram-negative  
   bacteria of, 320–322  
 position in evolutionary tree, 274*f*  
 position in taxonomic hierarchy,  
   279*f*  
 proteobacteria of, 303–314. *See also*  
   proteobacteria  
 summary of selected prokaryotes,  
   300–302*t*
- Domain Eukarya, **274**, 274*f*, 276*t*. *See*  
*also* eukaryotes  
 Kingdoms in, 274*f*  
 position in evolutionary tree, 274*f*  
 position in taxonomic hierarchy,  
   279*f*
- domain (taxonomic)  
 defined, **278**, 279*f*  
 of three-domain system, 6, 273–275,  
   274*f*, 276*t*
- domoic acid intoxication, **346**
- donor cells in gene transfers, 231*f*,  
 232–233, 234*f*
- doripenem, 569, 585*b*
- double helix, DNA, **47**, 48*f*, 208



- double-stranded DNA viruses, 388*t*  
 enveloped viruses, 377*t*, 388*f*  
 nonenveloped viruses, 377*t*  
 double-stranded RNA viruses, 388*f*, 388*t*  
 nonenveloped viruses, 378*t*  
 doxycycline, 571, 646  
 DPA (dipicolinic acid), 44*b*, 48*b*, 97  
*Dracunculus medinensis* (guinea worm), 14, 14*f*  
 drain cleaners, 2, 16  
 drinking water  
   chlorine gas to disinfect, 194  
   fecal contamination and, 356*t*  
   parasitic protozoa and, 356*t*  
 droplet transmission, 411–412, 412*f*  
 drotrecogin alfa (Xigris), 646  
 DRT/D value (decimal reduction time), 185  
 drug-induced cytotoxic reactions, 528, 529*f*  
 drug resistance, 12. *See also* antibiotic resistance  
 drugs  
   antibiotic, 11–12, 12*f*. *See also* antibiotics  
   antimicrobial, 553–583. *See also* antimicrobial drugs  
   synthetic, 11–12  
 dry heat sterilization, 188  
 dry weight, as measure of bacterial numbers, 176–177  
 drying, resistance to by gram-negative vs. gram-positive bacteria, 87*t*  
 DTaP vaccine, 621, 684  
   recommended schedule, 507*t*  
 Duchenne's muscular dystrophy, 16  
 ducks, influenza A viruses and, 18  
 ducts, of male reproductive system, 750, 751*f*  
 Dulbecco, Renato, 10*f*  
 dura mater, 616, 617*f*  
 dust mites, 530, 530*f*  
 Dutch elm disease, 341–342  
 dye derivatives, as antimicrobial agents, 12  
 dyes  
   acidic, 67  
   basic, 67, 86, 87*t*  
   inhibition in gram-negative vs. gram-positive bacteria, 87*t*  
 dysentery, 717  
   amebic. *See* amebic dysentery  
   bacillary. *See* shigellosis  
   balantidial, 356*t*  
   *Balantidium coli* causing, 353, 356*t*  
   epidemics, antibiotic resistance and, 235  
   *Shigella* causing, 311  
 dysuria, 746  
**E**  
 EAEC (enteroaggregative *E. coli*), 724, 728*b*  
 earache (otitis media), 312, 685, 685*f*, 686*b*  
 Earth's carbon cycle, *Pelagibacter ubique* role in, 303  
 earwax, 455  
 eastern equine encephalitis (EEE/*Togavirus*), 377*t*, 630, 634*b*  
 eating utensils, calcium hypochlorite (chloride of lime) to disinfect, 194, 201*t*  
 EB virus. *See* Epstein-Barr (EB) virus  
 EBLV (*European bat lyssavirus*), 630  
 Ebola hemorrhagic fever (EHF), 19, 666, 667*b*  
   as emerging infectious disease, 19, 20, 419*t*, 666  
 Ebola virus, 659*f*, 666, 667*b*  
   emerging infectious diseases and, 19, 20, 419*t*, 666  
   as filovirus, 373*f*, 378*t*  
   as helical virus, 373, 373*f*  
   as potential biological weapon, 654*b*  
   size of, 372*f*  
 echinocandin antifungal drugs, 566*t*, 574  
*Echinococcus granulosus*, 359–360, 361*f*, 364*t*  
*Echinococcus multilocularis*, 361*f*  
 echoviruses, 377*t*, 396*t*  
   as opportunistic pathogens, 405  
 eclipse period in viral multiplication, 381*f*, 383, 385  
 ecological niche (host range), viral species and, 375  
 ecology, microbial, 15  
 EcoRI restriction enzyme, 248*t*, 249*f*  
 ecosystems, without sunlight, 779–780  
 ectomycorrhizae, 773, 774*f*  
 ectopic pregnancies, pelvic inflammatory disease and, 752  
 ectosymbiosis, 106*b*  
 Edelman, Gerald M., 10*f*  
 edema, of inflammation, 466  
 edema toxin, of *Bacillus anthracis*, 650  
 EDTA (ethylenediaminetetraacetic acid), 88  
 EEE/*Togavirus* (eastern equine encephalitis), 377*t*, 630, 634*b*  
 efavirenz, 553, 575  
 eflornithine, to treat African sleeping sickness, 633  
 EGF (epidermal growth factor), 259*t*  
 eggs  
   embryonated, to grow viruses, 379, 379*f*, 504  
   food allergies and, 525  
   raw, *Salmonella tennessee* outbreak and, 294*b*  
 EHEC (enterohemorrhagic *E. coli*), 723*f*, 724, 728*b*  
 EHF (Ebola hemorrhagic fever), 19, 419*t*, 659  
 Ehrlich, Paul, 10*f*, 12, 479, 480, 559  
*Ehrlichia chaffeensis*  
   ehrlichiosis caused by, 290, 654  
   Lone Star tick as vector, 654  
   PCR used to identify, 290, 654  
*Ehrlichia* genus/spp., 300*t*, 304  
   arthropod vectors that transmit, 413*t*  
   ehrlichiosis and, 290, 304, 364*t*, 413*t*, 654, 656*b*  
   reservoirs/transmission method, 413*t*  
 ehrlichiosis, 290, 304, 364*t*, 413*t*, 414*t*, 656*b*, 660  
   disease reservoirs for, 413*t*  
   human granulocytic, 290, 660  
 human granulocytic anaplasmosis, 290, 424*t*, 656*b*, 660  
*Ixodes* spp. tick as arthropod vector, 414*t*  
   as notifiable infectious disease, 424*t*  
   transmission due to, 413*t*  
 EIA (enzyme immunoassay), 519, 683, 761  
 EIDs. *See* emerging infectious diseases  
 EIEC (enteroinvasive *E. coli*), 723, 728*b*  
 80S ribosomes, 94, 100*t*  
 electrolyte imbalances, fever and, 466  
 electromagnetic fields, in plasma sterilization, 201, 205*t*  
 electromagnetic lenses, used in electron microscopes, 61–64, 63*f*  
 electron acceptors, 29, 29*f*  
   final, 131, 139, 141*f*  
 electron-beam accelerator (in food preservation), 804, 804*f*  
 electron carriers, in energy production, 139, 141*f*  
 electron donors, 29, 29*f*  
   in energy production, 141*f*, 147  
 electron microscopes/microscopy, 14, 61–64, 63*f*, 66*t*  
   to diagnose *H. pylori* peptic ulcer disease, 64*b*  
   viral sizes and, 14, 370, 372*f*  
 electron shells, 26*f*, 27, 28*t*  
 electron transport chain (system), 121, 127–130, 127*f*, 129*f*  
   ATP synthesis/yields and, 128–130, 128*f*, 129*f*, 130*t*  
   catabolism and, 136*f*  
   in cellular respiration, 123*f*  
   in eukaryotic cells, 127, 129*f*  
   mitochondrial, 127, 127*f*, 129  
   oxidative phosphorylation and, 120–121, 127*f*  
   in photosynthesis, 138, 139*f*  
   in prokaryotic cells, 127, 129*f*  
 electronic cell counters (Coulter counters), 175  
 electronic configurations, 27, 28*f*, 28*t*  
 electrons, 26, 26*f*  
   in cellular oxidations, 120, 120*f*, 121*f*  
   chemical bonds and, 27–31  
   of electron microscopes, 61–64, 63*f*  
   in ionizing radiation, mutagens and, 227  
 electrophoresis. *See* gel electrophoresis  
 electroporation, 251  
 elementary bodies, *Chlamydia psittaci* and, 322, 323*f*, 372*f*, 695  
 elements  
   trace, activating enzymes and, 115  
   trace, microbial requirements, 158  
 elements (chemical), 26–27, 27*t*  
   common to organic compounds, 36  
   isotopes, 26–27  
 elephantiasis, 446  
 ELISA (enzyme-linked immunosorbent assay), 286, 287*f*, 519–522, 523*f*  
 HIV antibodies detected by, 521, 523*f*, 545  
 for syphilis, 755  
*Toxoplasma gondii* detected by, 352  
 elk, chronic wasting disease (prion-caused), 636  
 Ellerman, Wilhelm, 392  
 elm trees, Dutch elm disease and  
   *Ceratocystis ulmi* fungus, 341–342  
 embalming chemicals, 197  
 Embden-Meyerhof pathway, 122. *See also* glycolysis  
 embryonated eggs  
   to culture animal viruses, 379, 379*f*  
   influenza viruses grown in to make vaccine, 508*f*  
 embryonic stem cells (ESCs), 540, 540*f*  
 emerging infectious diseases (EIDs), 17–20, 330, 417–419, 418, 419*t*  
   criteria for identifying, 418  
   factors contributing to, 18, 207, 418  
   genetics and, 207  
   by microbe/year/disease, 419*t*  
   vaccine development and, 506  
*Emerging Infectious Diseases* (scientific journal), 418  
 emerging viral hemorrhagic fevers, 637, 659–660, 667*b*  
 emtricitabine, 553, 575  
 emulsification, 196  
 enanthem rashes, 591  
 encephalitis, 356*t*, 616, 623*b*, 634*b*  
   AIDS-associated, 550*t*  
   arboviral, 630–632, 632*f*, 634*b*  
   aseptic, 220*b*  
   *Balamuthia* causing, 351, 356*t*  
   California encephalitis serogroup, 378*t*, 631, 631*f*, 634*b*  
   eastern equine encephalitis (EEE), 377*t*, 630, 634*b*  
   fatal, from rabies, 629  
   granulomatous amebic, 623*b*, 635  
   Hendra virus causing, 419*t*  
   Japanese, 631–632  
   *Lyssavirus* related, 630  
   Nipah virus causing, 419*t*  
   as potential biological weapon, 654*b*  
   progressive, 396*t*  
   raccoon roundworm causing (*Baylisascaris procyonis*), 419*t*  
   spongiform encephalopathies and, 395  
   St. Louis encephalitis (SLE), 377*t*, 630, 634*b*  
   subacute sclerosing panencephalitis (SSPE), 394, 396*t*  
   West Nile, 19, 220*b*, 220*f*, 631, 634*b*  
   western equine encephalitis (WEE), 377*t*, 630, 634*b*  
*Encephalitozoon intestinalis*, 337*f*  
 encephalopathies, spongiform, 395  
 encystment in protozoa, 349  
 end-product, defined, 118  
 end-product inhibition (feedback inhibition), 118–119, 119*f*  
 end-products of fermentation, 132–133, 132*f*, 134*t*  
   industrial/commercial uses, 134*t*  
 endemic disease, 406  
 endemic murine typhus, 304, 364*t*, 413*t*  
   causative agent/arthropod vector, 413*t*

- Rickettsia typhi* causing, 304  
*Xenopsylla* (rat flea) as vector transmitting, 364t
- endergonic reactions, 31, 112
- Enders, John F., 13t
- endo medium, for enumerating coliforms, 177f
- endocarditis, 647–648, 647f, 649b  
 acute bacterial, 648, 649b  
 gonorrheal, 755  
 subacute bacterial, 647–648, 647f, 649b  
 vancomycin-resistant enterococci and, 419t
- endocardium, 647
- endocytosis, 100, 385, 385t  
 receptor-mediated, 100–101
- endoflagella (axial filaments), 82, 83f, 325, 325f
- endogenous antigens, 493
- endogenous pyrogen. *See* interleukin-1
- endoliths, 779–780
- endomycorrhizae (vesicular-arbuscular mycorrhizae), 767, 768f, 769f
- endonucleases, 211t, 227, 228f
- endoplasmic reticulum (ER), 102, 103f  
 rough, 98f, 102, 103f  
 smooth, 102, 103f
- endoscopes, peracetic acid and, 201
- endospore suspensions, to test for successful sterilization, 187
- endospores, 70–71, 70f, 71t, 95–97, 96f, 314f, 315f  
 alcohols' effectiveness against, 194, 202t  
 antimicrobials effective against, 201t  
 autoclaving and, 185, 187  
 of *Bacillus*, 43b, 44b, 48b, 301t, 314, 315–316, 315f  
 boiling water survival time and, 97, 185  
 chemical antimicrobials activity against, 203, 203t  
 chlorine dioxide activity against, 194, 198  
 of *Clostridium*, 301t, 314, 314f  
 desiccation resistance and, 189  
 effects of high pressure on, 189  
 equivalent treatments to destroy, 188  
 ethylene oxide and, 198  
 in foodstuffs, radiation doses needed to kill, 797t  
 fungal spores vs., 333t, 334  
 heating to destroy, 182, 185  
 iodine and, 193  
 plasma sterilization and, 199  
 quats ineffective against, 196  
 resistance to chemical biocides, 200f, 200t  
 staining of, 70–71, 70f, 71t  
 of thermophilic bacteria, 97, 156
- endosymbiosis/endosymbiotic theory, 105, 106b, 275, 275f, 276t  
*Wolbachia* and, 306, 308b
- endothelial cells, 453
- endotoxic shock (gram-negative sepsis), 440, 646
- endotoxins, 87t, 95b, 437f, 439–441, 440f, 442t  
 antitoxins and, 442t
- autoclaving and, 441, 442b, 442t, 444b
- blood-clotting proteins activated by, 440
- exotoxins vs., 437f, 442t
- fever and, 88b, 440f, 442t
- gram-negative bacteria and, 440, 442t
- as immunotherapy for cancer patients, 542
- lethal dose and, 442t
- lipid A as, 88b, 440, 442t
- as lipopolysaccharides, 440, 442t
- mechanisms of action, 437f, 442t
- as pathogenicity mechanism, 447f
- properties of, 442t
- symptoms induced by, 95b, 440, 442t
- testing for presence of, 441, 442b, 444b
- toxicity of, 442t
- ultrasound baths to detect, 442b, 444b
- energy (chemical), 31  
 activation, 113, 114f, 115, 115f  
 anabolism and, 112, 112f. *See also* anabolism  
 ATP and, 47–49, 49f. *See also* ATP  
 catabolism and, 112, 112f. *See also* catabolism  
 collision theory and, 113  
 electrons and energy levels, 27  
 endergonic vs. exergonic, 31  
 organisms classified by their source of, 140–143, 141f  
 potential, 120, 139  
 production of. *See* energy  
 production mechanisms  
 radiant, 190, 190f  
 requirements  
 for chemical reactions, 113, 114f  
 microbes classified by source of, 140, 141f  
 sources, 37, 139–140, 141f  
 storage of, 144, 147  
 supply in DNA replication, 213
- energy production mechanisms, 119–121  
 aerobic respiration, 127–130, 131f, 139, 141f  
 anaerobic respiration, 127, 130, 135t, 139, 141f  
 ATP yields and, 130t, 131f, 132f, 133f, 135t  
 carbohydrate catabolism and, 122, 123f. *See also* carbohydrate metabolism  
 comparison of, 135t  
 fermentation, 122, 123f. *See also* fermentation  
 lipid catabolism and, 133–135, 135f, 136f  
 metabolic pathways and, 121  
 oxidation-reduction reactions, 115t, 120, 120f, 139, 141f  
 photosynthesis, 138, 139f  
 protein catabolism and, 134–135, 136f  
 summary of, 139–140, 141f
- enfuvirtide, 553, 576–577
- enrichment culture media, 165–166, 167t
- Entamoeba*, 351
- Entamoeba dispar*, 351, 356t
- Entamoeba histolytica*, 350–351, 351f, 356t, 738, 738f, 740b
- enterics, 310–312. *See also* Enterobacteriales  
 bacteriocins produced by, 310, 403  
 biochemical tests to identify, 284–286, 284f, 285f, 286f, 310–312  
 clinical importance of, 310  
 specialized sex pili and, 235f, 310
- enteritis, giardial, 356t
- enteroaggregative *E. coli* (EAEC), 724, 728b
- Enterobacter aerogenes*, 312
- Enterobacter cloacae*, 312
- Enterobacter* genus/spp., 301t, 312  
 biochemical tests to identify, 284, 284f, 285–286, 285f  
 fermentation and, 132f, 310  
 as normal microbiota of large intestine, 310, 404t  
 nosocomial infections and, 312, 416t  
 as superbugs, 580
- Enterobacteriaceae (family), 279f, 284
- Enterobacteriales, 279f, 301t, 310–312  
 biochemical tests to identify, 284, 284f, 285–286, 285f  
 important genera/special features, 301t
- enterobactin, 436f
- Enterobius vermicularis*, 361, 362f, 364t, 740b, 741
- enterococci, 317, 640  
 causing septic shock, 649b  
 natural resistance to penicillin, 640  
 nosocomial infections and, 415, 416t  
 vancomycin-resistant (VRE), 419t, 563, 583b, 640
- Enterococcus faecalis*, 317  
 classification changes and, 278  
 indwelling catheters and, 317  
 nosocomial infections and, 317, 416t, 647  
 pentose phosphate pathway and, 125  
 as superbug, 580  
 surgical wound infections and, 317, 647  
 urinary tract infections and, 317, 647  
 vancomycin-resistant, 12, 647  
 transferred to *Staphylococcus aureus* via Tn1546 transposon, 237, 239
- Enterococcus faecium*, 317  
 classification changes and, 278  
 nosocomial infections and, 647  
 sepsis and, 647
- Enterococcus* genus/spp., 301t, 314, 317  
 classification changes and, 278  
 as normal microbiota of large intestine, 404t  
 as normal microbiota of urethra, 404t  
 nosocomial infections and, 415, 416t
- enterohemorrhagic *E. coli* (EHEC), 723f, 724, 728b
- enteroinvasive *E. coli* (EIEC), 723, 728b
- enteropathogenic *E. coli* (EPEC), 723, 728b
- enteropathogenic strains of *E. coli*, 442, 723
- enterotoxigenic *E. coli* (ETEC), 441t, 724, 728b
- enterotoxins, 438  
*Clostridium difficile* producing, 441t  
 diseases caused by, 441t  
*Escherichia coli* producing, 439, 441t  
 produced by *E. coli*, 310  
*Staphylococcus aureus* producing, 316, 439, 593  
 traveler's diarrhea and, 441t, 724  
*Vibrio cholerae* producing, 440, 441t
- Enterotube II, 285f
- Enterovirus, 377t  
 cytopathic effects of, 445t  
 pregnancy and, 760
- enterovirus infection, persistent, 396t
- Entner-Doudoroff pathway, 125  
 in purine/pyrimidine biosynthesis, 145–146, 146f
- Entomophaga*, as pest control, 341
- entry inhibitors, 576
- entry stage in viral multiplication, 385, 385t, 386f, 389f
- envelope, viral, 371, 373f
- enveloped viruses, 373, 373f  
 alcohol-based disinfectants and, 194, 202t  
 biguanide disinfectants and, 193  
 biocidal resistance and, 203, 203f  
 budding of, 392, 392f  
 double-stranded DNA, 377t, 388f, 392b  
 double-stranded RNA, 378t  
 entry stage in, 385, 386f  
 helical, 373, 373f  
 hepatitis B, 392b  
 hepatitis C, 392b  
 HIV as, 545, 546f  
 maturation stage in, 391–392  
 polyhedral, 373  
 quats active against, 196, 202t  
 single-stranded RNA, 375–378t, 388f
- environmental microbiology, 772–798  
 aquatic, 782–795  
 biogeochemical cycles, 774–782. *See also* specific cycles  
 biotechnology ethical/safety issues, 266–267  
 microbial diversity and, 327–328, 773  
*Pseudomonas* species possibilities in, 235  
 soil, 774–782  
 symbiosis and, 773–774
- enzyme immunoassay (EIA), 519, 683, 761
- enzyme-linked immunosorbent assay (ELISA), 286, 287f, 519–521, 522f, 523f  
 direct ELISA tests, 286, 514, 520, 523f  
 indirect ELISA tests, 514, 521, 523f

- enzyme poisons, 118  
 enzyme-substrate complex, **113**, **114f**, **115**, **116f**  
 enzymes, **41**, **113**–**119**, **433**–**435**  
   amylases, **38**  
   in bacterial plasma membranes, **90**, **92**  
   biochemical tests to detect, **135**–**137**, **137f**  
   as catalysts, **113**, **114**, **115t**  
   classification of, **114**, **115t**  
   coagulases, **434**  
   cofactors, **116**, **116f**, **158**  
   collagenase, **435**  
   collision theory and, **113**  
   components of, **114**–**115**, **114f**, **115t**  
   controls on synthesis of  
     induction, **219**, **221f**, **222f**  
     repression, **219**, **221f**, **222f**  
   denaturation of, **117**, **117f**  
   digestive, lysosomes and, **103**  
   in DNA replication, **210**–**215**, **211t**  
   efficiency of, **116**  
   enzyme poisons, **118**  
   extracellular, **92**, **320**, **433**–**435**  
   factors influencing, **116**–**118**, **117f**  
   filtration used to sterilize, **188**  
   genetics and, **113**  
   heat and, **113**, **116**–**117**, **117f**  
   hyaluronidase, **435**  
   inactivation of antibiotics by, **580**–**581**, **581f**  
   inducible, **219**–**221**, **221f**  
   inhibitors of, **118**–**119**, **118f**, **119f**  
   kinases, **434**  
   light-repair (photolyases), **211t**, **227**–**228**, **228f**  
   mechanism of action, **115**–**116**, **116f**  
   metabolic pathways and, **113**, **121**  
   microbial, used in stone-washed-jeans production, **2**, **3b**  
   naming of, **114**, **115t**  
   pathogenicity and, **433**–**435**, **447f**  
   phage lysozyme, **381**  
   photolyases, **211t**, **227**–**228**, **228f**  
   of prokaryotes, vs. eukaryotes, **101**  
   regulation of, **218**–**223**  
   restriction. *See* restriction enzymes  
   role in coordinating anabolic/catabolic reactions, **146**  
   specificity of, **113**–**114**, **116**  
   streptococci-produced, and tissue destruction, **286**, **317**  
   *streptomyces*-produced, to utilize soil proteins, **320**  
   substrates and, **113**, **117**, **117f**. *See also* substrates  
   synthesis of, **222**  
   temperature and, **113**, **116**–**117**, **117f**  
   turnover number and, **116**  
   virulence of pathogens and, **433**–**435**  
   viruses and, **381**, **383**, **385**  
 eosin dye, **67**  
 eosinophils, **456**, **457t**  
   adhering to parasitic fluke larvae, **495**, **496f**  
   in allergic reactions, **529**  
   histamine released by, **456**  
   produce toxins against parasites, **456**  
   as second line of defense, **452f**  
   staining and, **456**  
 EPEC (enteropathogenic *E. coli*), **723**, **728b**  
 epidemic disease, **406**  
 epidemic typhus. *See* typhus  
 epidemics, emerging infectious diseases and, **17**–**20**  
 epidemiologists, role in hospital infection control, **422**  
 epidemiology, **419**–**422**, **421f**  
   analytical, **421**  
   case reporting, **422**  
   descriptive, **420**–**421**  
   early efforts of Nightingale, Semmelweis, Snow, **419**  
   epidemiological graphs (examples), **420**, **421f**  
   experimental, **422**  
   information sources in, **422**  
   *MMWR*'s importance to, **422**  
   morbidity rate/mortality rate and, **422**  
   notifiable infectious diseases reports, **422**  
   public health departments, state and federal, **420**  
   topics of study, **419**–**222**  
 epidermal growth factor (EGF), **259t**  
 epidermis, **453**, **453f**, **590**, **590f**  
   cutaneous mycoses and, **340**, **340t**, **605**–**607**  
   fungal infections, **340**, **340t**  
   as physical barrier to microbes, **453**, **474t**, **589**  
 Epidermophyton, **340t**, **597b**, **605**–**606**  
   reservoirs/transmission method, **413t**  
 epididymitis, **755**  
 Epiduo, **599**  
 epigenetic inheritance, **222**  
 epiglottitis, **454**–**455**, **474t**, **681f**, **683**  
   *Haemophilus influenzae* type b and, **312**, **613**, **683**  
 epinephrine, anaphylactic shock and, **524**  
 epithelial cells  
   of mucous membranes, **451**  
   of skin, **451**  
 epithelium  
   cathelicidins produced by, **473**  
   defensins produced by, **473**  
   epitopes (antigenic determinants), **481**, **481f**, **487**, **487f**  
 EPO (erythropoietin), **259t**  
 EPS (extracellular polymeric substance), **80**  
 epsilonproteobacteria, **301t**, **303**, **313**  
 Epstein-Barr virus (EB virus/*Lymphocryptovirus*)  
   Burkitt's lymphoma associated with, **393**, **649b**, **662**–**663**, **663f**  
   cancer and, **393**  
   complement receptors and, **470**  
   diseases possibly associated with, **664**  
   incubation period, **431t**  
   infectious mononucleosis caused by, **431t**, **649b**  
   portals of entry, **431t**  
   pregnancy and, **760**  
   reactivated in HIV/AIDS patients, **549**  
   U.S. prevalence of antibodies against, **662**–**663**, **663f**  
 Epstein, Michael, **10f**, **392**  
 Epulopiscium fishelsoni, **315**, **315f**  
 Epulopiscium genus/spp., **301t**, **314**–**315**, **315f**, **327**  
 equilibrium, in simple diffusion process, **91**, **91f**  
 equivalent treatments, **188**  
 ER (endoplasmic reticulum), **102**, **103f**  
 ergot poisoning, **735**, **740b**  
 ergot toxin, **445**, **735**  
   as natural source LSD (lysergic acid diethylamide), **445**  
 ergotism, **445**  
 Erwinia genus/spp., **301t**, **311**–**312**  
 erysipelas, **317**, **406**, **595**, **595f**, **597b**  
 Erysipelothrix rhusiopathiae, **282b**  
 erythema infectiosum. *See* fifth disease  
 erythroblastosis fetalis. *See* hemolytic disease of newborn  
 erythrocytes (red blood cells), **457t**  
   agglutination by envelope spikes of influenza viruses, **378t**  
   blood agar and, **165**, **165f**  
   in inflammatory response, **464f**  
   parasites, *Plasmodium vivax*, **351**, **352f**  
 erythrogenic toxins, **439**, **442**, **442t**, **683**  
   *Streptococcus pyogenes*, **235**, **439**, **442t**  
 erythrolitin, dye extracted from lichens, **342**  
 erythromycin, **561f**, **565t**, **571**, **571f**  
   produced by *Saccharopolyspora erythraea*, **560t**  
   protein synthesis inhibited by, **94**, **565t**, **571**  
 erythropoietin (EPO), **259t**  
 Escherich, Theodor, **3**, **10f**  
 Escherichia coli, **3f**, **58f**, **310**, **405f**  
   adhesins on fimbriae, *Shigella* and, **431f**, **433**  
   agriculturally important products genetically modified in, **267t**  
   aztreonam effective against, **569**  
   bacteriocins produced by, **310**, **403**  
   bacteriophage lambda, lysogenic cycle and, **383**–**385**, **383f**  
   beneficial activities of, **19**  
   biochemical tests to identify, **136**, **137f**, **284**–**285**, **284f**, **285f**  
   as causing nosocomial infections, **414**, **414t**  
   cephalosporin resistance transferred to *Salmonella enterica* by, **583b**  
   chemically defined culture media recipe, **162**, **162t**  
   chemically defined medium for growing, **162t**  
   chromosome of, **209**, **209f**  
   competency for modification and, **251**  
   conjugation in, **234**, **236f**  
   cystitis caused by, **746**  
   directly damaging host cells, **436**  
   disinfectants and, **193f**  
   DNA of, **209**, **209f**  
   DNA replication in, **213**–**214**, **213f**  
   *E. coli* 0157:H7 strain, **19**, **310**  
   DNA fingerprinting tracks outbreak, **261**, **263f**  
   as an emerging infectious disease, **19**, **418**, **419t**  
   fimbriae and, **82**  
   genetic recombination and, **418**  
   H antigens and, **82**  
   hemolytic uremic syndrome (HUS) and, **718**  
   lipopolysaccharides and, **86**  
   naming of, **311**<sup>footnote</sup>  
   Shiga toxin gene and, **207**, **442**  
   sorbitol fermentation and, **136**  
   tomatoes and, **310**, **714**, **715b**  
 EcoRI restriction enzyme used in rDNA technology, **248t**  
 endotoxins produced by, **255**, **310**  
 enteroaggregative (EAEC), **724**, **728b**  
 enterohemorrhagic (EHEC), **724**, **728b**  
 enteroinvasive (EIEC), **723**, **728b**  
 enteropathogenic (EPEC), **723**, **728b**  
 enteropathogenic strains, **440**, **441t**, **442**, **723**–**724**, **728b**  
 enterotoxigenic (ETEC), **724**, **728b**  
 enzymes and feedback inhibition, **119**, **119f**  
   as facultative anaerobe, **159**  
   feedback inhibition in, **119**, **119f**  
   fimbriae of, **83**, **83f**  
   gastroenteritis caused by, **723**–**724**, **723f**, **728b**  
   genome mapped for, **261**  
   growth rate on glucose and lactose, **221**–**222**, **222f**  
   as important biological research tool, **310**  
   lactose metabolism in, **219**, **221**–**222**, **221f**, **222f**  
   mutualistic symbiotic relationships of, **405**, **405f**  
   as normal microbiota of large intestine, **402**, **404t**  
   nosocomial infections and, **415**, **416t**  
   as an opportunistic pathogen, **405**, **415**, **416t**  
   pentose phosphate pathway and, **125**  
   plasmid vector pUC19 used for cloning, **249f**  
   plasmids that code for pathogenic toxins, **235**  
   pyelonephritis caused by, **746**, **752**  
   R factor from, **238f**  
   RecA protein of, **64f**, **67t**  
 recombinant  
   colony-stimulating factor (CSF) produced by, **259t**  
   epidermal growth factor (EGF) produced by, **259t**  
   gamma interferon produced by, **255**–**256**, **256f**  
   human growth hormone and, **247**, **259t**  
   interferons and, **259t**  
   to produce gene products, **255**–**257**, **256f**



- to produce pharmaceutical products, 259*t*  
streptokinase produced by, 434*b*  
*Salmonella* strains, and host's plasma membrane, 435, 435*f*  
scanning electron microscope micrograph, 58*f*  
serovars and, 82  
Shiga toxin-producing (STEC), 207, 235, 384, 442, 711, 711*f*, 724, 728*b*  
Clinical Case, 712*b*, 723*b*, 727*b*, 734*b*, 742*b*  
as notifiable infectious disease, 424*t*  
size of, 372*f*  
sorbitol fermentation by and, 136  
in taxonomic hierarchy, 279*f*  
transduction in, 234–235, 237*f*  
traveler's diarrhea enterotoxins and, 439, 441*t*, 724  
twitching motility of, 83  
urinary tract infections caused by, 752  
used in indigo production, 3*b*, 3*f*  
*Escherichia* genus/spp., 279*f*, 301*t*, 310  
biochemical tests to identify, 136, 137*f*, 284–285, 284*f*, 285*f*  
as an enteric, 284, 301*t*, 310  
fermentation tests and, 136–137, 137*f*  
resistance plasmid R100 and, 236–237, 238*f*  
ESCs (embryonic stem cells), 540, 540*f*  
ester functional group, 36*t*  
ester linkage, 39, 39*f*  
ETEC (enterotoxigenic *E. coli*), 724, 728*b*  
ethambutol, 564*t*, 569  
ethanol, 37  
as a biofuel, 814  
*Acetobacter* and, 137, 304  
biotechnology and, 244  
as disinfectant, 194–195, 194*t*, 202*t*  
fermentation and, 132*f*, 133, 133*f*, 134*t*, 332  
*Gluconobacter* and, 304  
as primary metabolite of industrial fermentation, 809, 810*f*  
ethanol produced by yeasts, 137, 334  
ether functional group, 36*t*  
ethical issues, of genetic modification, 266–267  
ethylene oxide gas, 183*t*, 198  
vs. hydrogen peroxide gas, 199  
ethylenediaminetetraacetic acid (EDTA), 88  
etiology of disease, 402  
*Eucalyptus* trees, infected by  
*Phytophthora cinnamoni*, 348  
*Euglena*, 5, 99, 99*f*, 350*f*  
Euglenoids, 344*f*, 349–350, 350*f*  
Euglenozoa, 349–350, 350*f*, 356*t*  
position in evolutionary tree, 274*f*  
Eukarya (domain), 6, 274, 274*f*  
algae of, 343–348. *See also* algae  
animals of, 274, 274*f*. *See also* animals  
Archaea domain vs., 274*f*, 276*t*  
Bacteria domain vs., 276*t*  
fungi of, 331–342. *See also* fungi  
helminths of, 354–362. *See also* helminths  
kingdoms in, 274*f*, 280–281  
plants of, 274, 274*f*. *See also* plants  
protozoa of, 345–351. *See also* protozoa  
taxonomic hierarchy of, 278, 279*f*  
vs. other domains, 276*t*  
eukaryotes/eukaryotic cells, 4, 75, 76, 97–106, 98*f*  
active transport processes used by, 93  
ancestral, 105  
arthropods as vectors and, 363, 363*f*, 364*t*  
cell division in, 76, 100*t*  
characteristics that distinguish, 76  
classification of, 274*f*, 279*f*, 280–281  
cloning genes from, 253, 254*f*  
DNA arrangement of, 76, 100*t*  
evolution, 101, 105, 274*f*, 275–277, 275*t*  
*Cyanophora paradoxa* as modern example of, 275, 275*f*  
genetic recombination in, 231  
mutation identification and, 231  
nucleus, and prokaryotic *Gemmata obscuriglobus*, 322, 322*f*  
origin of, 101, 105, 274*f*, 275–277, 276*t*, 277*f*, 322  
pathogenic, 330  
photosynthesis in, compared to prokaryotes, 143*t*  
plasmids and, 238  
prokaryotes vs., 76, 81, 82, 100*t*, 274, 276*t*, 277  
prokaryotic cells vs., 100*t*, 105  
protein synthesis in, 218, 219*f*  
ribosomal differences, 93  
size of, 76, 100*t*  
species of, vs. prokaryotic species, 278, 280  
structure  
cell wall, 76, 79*f*, 81, 98*f*, 99–100, 100*t*  
cytoplasm, 98*f*, 100–101, 100*t*  
flagella/cilia, 98*f*, 99, 99*f*, 100*t*  
glycocalyx, 99–100, 100*t*  
organelles, 76, 100*t*, 101–105, 276*t*  
as vehicles for expressing genetically modified genes, 256–257  
*Eunotia*, 346*f*  
*European bat lyssavirus* (EBLV), 630  
European corn borer, 266  
Euryarchaeota, 302*t*  
eutrophication, 785  
evaporated milk, 343  
evaporating ponds, extreme halophiles found in, 326  
evolution, 101, 105  
*Carsonella ruddii*'s small genome and, 326  
cladograms to map, 293–294, 294*f*  
cyanobacteria fossil evidence, 320–321  
definition of, 273  
degenerative, 318  
EIDs and, 18  
endosymbiotic theory and, 105  
of eukaryotes, 101, 105  
genetic recombination and, 231  
genetically modified crops and, 266–267  
microbial pathogenicity, virulence and, 429  
molecular clock and, 277  
mutation rates and, 228  
natural selection and, 273  
phylogeny and, 273  
prokaryotes and, 105  
ribosomes and, 101  
systematics and, 273  
of the three domains, 273–275, 274*f*, 276*t*  
transposons as powerful mediator in, 239  
universal ancestors and, 274*f*, 275, 275*f*, 277  
*Wolbachia* and, 308*b*  
evolutionary relationships  
cladograms to map, 293–294, 294*f*  
rRNA sequencing/ribotyping to trace, 292  
study of, 273–277  
evolutionary tree  
*Thermotoga* and, 277  
the three-domain system, 274, 274*f*  
exanthem rashes, 591  
Excavata superkingdom, 349, 350*f*  
exchange chemical reactions, 32, 37  
exchange reactions, 37  
exergonic chemical reactions, 31, 112, 213  
hydrolysis, 213  
exfoliation, 593, 593*f*  
exfoliative toxins, 235, 593  
exoenzymes (extracellular enzymes), virulence and, 433–435  
exons, 211*t*, 218, 219*f*, 253, 254*f*  
exonucleases, 211*t*  
exotoxins, 41, 87*t*, 437–439, 437*f*, 438*f*, 441*t*, 442*t*  
A, 596  
altered (inactivated) as toxins, 438, 442*t*  
diseases caused by, 441*t*, 442*t*  
endotoxins vs., 442*t*  
as enzymes, 437  
lethal dose and, 438, 442*t*  
mechanism of action, 437, 437*f*  
naming of, 438  
as pathogenicity mechanism, 447*f*  
properties of, 442*t*  
symptoms induced by, 437, 441*t*, 442*t*  
toxicity of, 442*t*  
types of, 438–439  
experimental epidemiology, 422  
exponential growth phase (log phase), in bacterial growth, 170, 170*f*  
expression, gene, 208, 210*f*, 218–223  
extensively drug-resistant (XDR) strains of tuberculosis, 691  
extinct plants/animals, DNA extraction and, 263  
extracellular antigens, in humoral immunity, 485, 486*f*, 496*f*, 500*f*  
extracellular enzymes (exoenzymes) in facilitated diffusion, 91*f*, 92  
lipases and, 134, 135*f*  
peptidases, 134–135  
proteases, 134–135  
virulence and, 433–435  
extracellular polymeric substance (EPS), 80  
extrachromosomal genetic elements (plasmids), 94  
extreme acidophiles, 326  
extreme halophiles, 4, 158, 274, 274*f*, 280*f*, 326  
extreme thermophiles (hyperthermophiles), 4, 156, 157*b*, 274, 274*f*, 280*f*, 302*t*, 326, 326*f*  
extremophiles, 326, 773. *See also* under extreme  
extremozymes, 773  
Exxon Valdez oil spill (1989), bacterial cleanup of, 32, 781  
eyelids, 454, 454*f*  
eyepiece (ocular lens), 55, 55*f*  
eyes  
infections  
*Moraxella* bacteria and, 309  
TASS, 430*b*, 436*b*, 442*b*, 444*b*, 446*b*  
lacrimal apparatus/tears produced by, 454–455, 454*f*  
microbial diseases of, 609–611, 609*b*  
normal microbiota of, 404*t*  
toxic anterior segment syndrome (TASS), 436*b*  
eyespots  
of euglenoids, 349, 351*f*  
of green algae, 345*f*  
**F**  
F cells. *See* F factor  
F factor (fertility factor), 234, 236*f*  
as conjugative plasmid, 235  
F<sup>+</sup>/F<sup>-</sup> cells, 84, 94, 234, 236*f*  
FA tests. *See* fluorescent-antibody (FA) tests  
facilitated diffusion, 91–92, 91*f*  
FACS (fluorescence-activated cell sorter), 518, 521*f*  
factor B complement protein, 467, 468*f*, 470*f*  
factor D complement protein, 467, 468*f*, 470*f*  
factor P (properdin) complement protein, 467, 468*f*, 470*f*  
Factor VII, 259*t*  
Factor VIII, 259*t*  
facultative anaerobes, 159, 159*t*  
fungi as, 332, 333*t*  
facultative halophiles, 158  
FAD (flavin adenine dinucleotide), 114  
as electron carrier, 141*f*  
in electron transport chain, 129–130, 129*f*  
in Krebs cycle, 125, 126*f*  
oxidative phosphorylation and, 120–121  
FADH<sub>2</sub>  
in electron transport chain, 129–130, 129*f*  
in Krebs cycle, 122, 126, 126*f*, 127  
fallopian (uterine) tubes, 750, 750*f*  
famciclovir, 575, 602

- FAME (fatty acid methyl ester) profiles, **287**
- familial disorders, 395
- family (taxonomic), defined, **278**, **279f**
- farm animals
- antibiotics in animal feed, 559, 562*t*, 565, 575, 583*b*
  - antibiotic resistance and, 583*b*
  - linked to human disease, 583*b*
  - anthelmintic (ivermectin) to treat, 571
  - as disease reservoirs, 413*t*
- farmers/gardeners, sporotrichosis and, 340
- Fasigyn (tinidazole), 571
- fastidious microorganisms, 162
- chemically defined media to grow, 162, 163*f*
  - transport media for pathogenic, 283
- fatal colitis, 404
- fatal familial insomnia, 395
- fats (triglycerides), 39–40, 39*f*
- in lipid catabolism, 133–135, 135*f*, 136*f*
  - synthesis of, 144, 145*f*
- fatty acid profiles (FAME), **287**
- fatty acids, 39, 39*f*
- bacteria, petroleum products and, 134
  - cis* fatty acids, 39–40, 39*f*
  - in lipid catabolism, 134, 135*f*, 136*f*
  - in lipids biosynthesis, 144, 145*f*
  - in plasma membrane, 89, 89*f*
  - saturated, 39–40, 39*f*
  - synthesis, biotin and, 115*t*
  - trans* fatty acids, 40
  - unsaturated, 39–40, 39*f*
- Fc region of antibodies, 482, 482*f*, 523–524, 524*f*
- fecal contamination
- coliform bacteria enumeration and, 172, 174*f*
  - norovirus and, 182*b*, 197*b*, 199*b*, 201*b*
- fecal contamination of drinking water, 356*t*
- fecal-oral cycle, **711**
- fecal-oral route of viral transmission, hepatitis A, 392*b*
- fecal samples
- differential media and, 286*b*, 287*b*, 290*b*, 293*b*, 294*b*
  - enrichment mediums and, 166, 286*b*, 287*b*
  - enterococci and, 317
  - stool DNA test, 208*b*
- feces, 706, 712
- Bacteroides* plentiful in, 322
  - phenolics to disinfect, 192
  - as portal of exit, 446
- feedback inhibition (end-product inhibition), **118–119**, 119*f*
- in regulation of amino acid production, 119
  - in regulation of gene expression, 218–223
- feeding grooves, **349**
- feline AIDS, 379
- feline leukemia virus (FeLV), 393
- vaccine, 259*t*, 543
- female reproductive system, **750**, 751*f*
- bacterial diseases of, 754–766, 766*b*, 767*b*
- fermentation, **8**, 122, **130–133**, 132*f*, **134b**
- aerobic respiration vs., 135*t*
  - alcohol, **133**, 133*f*, 134*t*
  - anaerobic respiration vs., 135*t*
  - ATP yields and, 132*f*, 133*f*, 135*t*
  - end-products of, 132*f*, 134*t*
  - final electron acceptor in, 135*t*, 141*f*
  - growth conditions and, 135*t*
  - identifying bacteria and, 284, 284*f*
  - industrial uses for, 134*t*, 808–810
  - lactic acid, **132–133**, 133*f*, 134*t*
  - of mannitol, 165, 166*f*
  - of milk products, 798–799, 799*f*
  - overview, 123*f*
  - phosphorylation used to generate ATP, 135*t*
  - types of, 132–133, 133*f*
- fermentation test, **136**, 137*f*
- ferns, as eukarya, 6
- ferritin, 436, **473**
- ferrous iron, as energy source, 143
- fertility factor. *See* F factor
- fetal calf serum, 495
- fetus
- genetic screening and, 261
  - group B streptococcal infections and, 320*b*, 324*b*
  - IgG antibodies and, 483*t*
  - immune system tolerance of, 534–535
  - rejection as nonself and, 534–535
- fever, 452*f*, **466**, **474t**
- Babesia microti* causing, 352
  - complications of, 466
  - crisis stage in, **466**
  - cytokines and, 440, 440*f*, 466
  - death and, 466
  - Plasmodium vivax* causing, 351–352
  - prostaglandin synthesis and, 440, 440*f*
  - as response to endotoxins, 440, 440*f*, 441*i*, 466
  - as second line of defense, 452*f*, 466, 474*t*
  - shivering and, **466**
  - Streptococcus pyogenes* causing, 406
  - tumor necrosis factor alpha and, 466
- fever blisters, 394, 396*t*. *See also* cold sores
- fibrinogen, 463
- fibrinolysin (streptokinase), 434, 434*b*, 590, 677
- fibrosis, in forming scar tissue, 465
- fibrous proteins, shape/structure of, 44, 45*f*
- fifth disease (erythema infectiosum), 377*t*, 385, 531*b*, 594*b*, **605**
- human parvovirus B19 causing, 594*b*, 605
  - macular rash caused by, 594*b*
- 50S ribosomes, 94, 94*f*
- filament of flagella, 81, 81*f*
- filamentous bacteria, 302*t*, 319, 319*f*, 320, 320*f*
- plate counts and, 177
  - as reproductive method, 168, 320
  - as soil inhabitants, 319–320
- filamentous fungi, advantages of, 320
- filamentous streamers, biofilms and, 161
- Filoviridae, **378t**
- Filovirus, 373*f*, 378*t*
- Ebola virus as, 373, 373*f*
- filterable agents, 369, 370
- filterable viruses, 188
- filters
- HEPA, **188**
  - membrane filters, **188**, 188*f*
- filtration
- to control microbial growth, 174*f*, **188**, 188*f*, 191*t*
  - to count/sterilize bacteria, **172**, 174*f*, 188, 188*f*
  - HEPA filters and, 188
  - sterilizing liquids or gases by, 182
  - water treatment, 788, 788*f*
- fimbriae/fimbria, **82–83**, 83*f*, **433**
- of enterics, 310
  - of *Neisseria gonorrhoeae*, 433
  - of prokaryotic cells, 79*f*, 307*f*
  - of uterine (fallopian) tubes, 751*f*
  - virulence factors and, 442
- final electron acceptor, 131, 135*t*, 141*f*
- fungi, cutaneous mycoses and, 340
- Fire, Andrew, 13*t*
- fire ants, 348
- Firmicutes (low G + C ratios), 3, 301*t*, **314–318**
- important genera/special features, 301*t*
- fish
- anisakines* roundworms and, 362, 364*t*
  - food allergies and, 525
  - Gambierdiscus toxicus* and, 347
  - Karenia brevis* and, 346
  - killed by toxic marine algae, 344
  - Pfiesteria* and, 347
  - red tides and, 346–347
  - tapeworm infection, 739
- FISH (fluorescent in situ hybridization), 282*b*, **292**, 293*f*, 707
- Fisher, Edmond H., 13*t*
- fission yeasts, **333–334**
- FITC (fluorescein isothiocyanate), 59
- FITC (fluorescein isothiocyanate), 59
- five-kingdom system, Whittaker's proposal of, 273
- 5'  $\Rightarrow$  3' direction, 211*f*, 212–213, 212*f*, 217
- 5-bromouracil, 226–227, 227*f*
- fixed macrophages (histiocytes), **460**, 638, 639*f*
- fixed specimens, **67**
- electron microscopes and, 62
- fixing specimens. *See* fixed specimens
- FK506 (Tacrolimus), 542
- flaccid paralysis, caused by botulinum toxin, 439, 622
- flagella/flagellum, 4, 70*f*, **71**, **81**, **99**
- of alga, 99, 99*f*, 345*f*, 346*f*
  - of animal cells, 98*f*, 99
  - bacterial, 4, 70*f*, 71, 79*f*, 81–82, 81*f*, 82*f*, 87*t*
  - of *Burkholderia*, 306–307
- of *Campylobacter*, 313
- of *Chilomastix*, 350*f*
- of dinoflagellates, 344*f*
- energy use and, 82
- of *Euglena*, 99, 99*f*, 350, 351*f*
- of eukaryotes vs. prokaryotes, 81, 99, 100*t*
- evolutionary aspects, 105
- of giant bacteria *Epulopiscium fishelsoni*, 315
- of *Helicobacter*, 313, 314*f*
- motility and, 81–82, 82*f*, 99, 100*t*
- of oomycete spores (zoospores), 344, 345*f*
- preemergent, of *Euglena*, 349, 350*f*
- of *Proteus mirabilis*, 311, 311*f*
- of protozoa, 99, 99*f*, 106*b*, 349, 350*f*
- staining of, 62, 70*f*, **71**, 71*t*
- of *T. sphaerica*, 106*b*
- of *Trichomonas vaginalis*, 349, 350*f*
- flagellin, 81
- Flagyl (metronidazole), to treat vaginitis caused by *Trichomonas vaginalis*, 571
- flaming (dry heat sterilization), **188**, 191*t*
- flat sour spoilage, of canned foods, **800–801**
- flatus, 712
- flatworms, 6, 355, **356–358**, 358*f–361f*, 364*t*
- flavin adenine dinucleotide (FAD), **114**
- in electron transport chain, 129–130, 129*f*
  - oxidative phosphorylation and, 120, 121*f*
- flavin coenzymes, 114, 129
- flavin mononucleotide (FMN), **114**
- in electron transport chain, 129–130, 129*f*
- Flaviviridae, **377t**, 390*b*
- Flavivirus, 377*t*, 667*b*
- reservoirs/transmission method, 413*t*
  - St. Louis encephalitis caused by, 377*t*, 625–626, **628b**
  - West Nile virus tracking and, 220*b*
- flavoproteins, 115*t*, **127**, 127*f*
- flavoring, fermentation end-products and, 134*t*
- fleas, 363, 363*f*, 364*t*
- diseases transmitted by, 304, 311, 364*t*, 413*t*
  - Rickettsia typhi* and, 304
  - rat (*Xenopsylla*), 363*f*
  - as vectors, 363*f*, 364*t*, 413*t*, 648
- Fleming, Alexander, 10*f*, 12, 12*f*, 455, 559
- flesh-eating bacteria, **19**, 287, 317, 320, 423*b*, 595, 595*f*
- flies
- deer (*Chrysops*), 363*f*
  - diseases transmitted by, 356*t*, 363
  - sand, 356*t*
  - true, 364*t*
  - tsetse, 350, 356*t*, 364*t*, 413*t*, 627–628
  - as vectors, 363*f*, 364*t*
- floc formation in activated sludge systems, 161, 790, 791*f*
- flocculating agents, 194

- flocculation, **788**  
*flora*. See normal microbiota  
 Florey, Howard, 10f, 559  
 flow cytometry/cytometer, **287–289**, 519, 521f  
 flu. See influenza  
 fluconazole, 332b, 574  
 flucytosine, 342b, 566t, 574, 633  
 fluid mosaic model, **90**  
 flukes (trematodes), 356–358, 358f, 359f, 364t, 738f  
   immune system attack on, 495, 496f  
   praziquantel to treat, 562t  
 fluorescein isothiocyanate (FITC), 59  
 fluorescence, **59**  
 fluorescence-activated cell sorter (FACS), **518**, 521f  
 fluorescence microscopy, **59**, 61f, 65t  
 fluorescent-antibody (FA) technique, **59**, 61f, 65t, 352, **518–519**, 520f  
 fluorescent in situ hybridization (FISH), 282b, 292, 293f, 707  
 fluorescent treponemal antibody absorption (FTA-ABS) test, 61f, 761–762  
 fluoride  
   calcium and, 118  
   as an enzyme poison, 118  
   magnesium and, 118  
 fluorochromes (fluorescent dyes), 59, 61f  
 fluoroquinolones (FQ), 423b, 565t, 572, 583b  
   in chicken feed, 583b  
   *Neisseria gonorrhoeae* resistant, 750, 751b  
   resistant *Campylobacter jejuni* and, 583b  
 FMN (flavin mononucleotide), **114**  
   in electron transport chain, 129–130, 129f  
 focal infection, **409**  
 folic acid, 115t  
   synthesis of, 118  
 foliose lichens, 342, 343f  
 follicular helper T cells (T<sub>HH</sub>), **492**  
 folliculitis, **588**, **593**, **597b**  
 fomites, **411**, 412f, 413t, 416, 447  
 fomivirsen, 579, 658  
 food acquisition methods  
   of algae, 331f, 344–345  
   of amebae, 350  
   of animals, 280, 333  
   of archaea, 326  
   of flukes, 356  
   of fungi, 280, 331f, 332, 333t  
   of helminths, 331f, 354, 356  
   of plants, 280  
   of protozoa, 331f, 349  
   of viruses, 280  
 food allergies, 528t, 530–531  
 food-associated infections, phage typing to trace, 287, 289f  
 food canning  
   home, 185, 187  
   industrial, **800–801**, 801f  
 food industry. See food production  
 food poisoning, **441t**. See also gastroenteritis  
   algae responsible for, 343  
   botulism. See botulism  
   *Clostridium perfringens* and, 441t  
   endospores and, 96  
   exotoxins causing, 441t  
   mushrooms, 735, 740b  
   *Salmonella* and. See salmonellosis  
   shellfish, 344, 356t, 446  
   staphylococcal, 316, 441t, **717–717**, 717f, **721b**, 728b  
   symptoms, 441t  
   vectors transmitting bacteria that cause, 413–414  
 food preservation  
   by adding antibiotics, 197  
   by aseptic packaging, **801–802**, 802f  
   by chemical additives, 197, 202t  
   by commercial sterilization, **182**, 183t, 185, 594f, **800–801**, 801f, 802f  
   HACCP system to prevent contamination in, **800**  
   by heat, 182, 183t, 185–188, 191t  
   by high-pressure processing, 804  
   home canning and, 185, 187  
   by irradiation, 803–804, 804ff, 804t  
   by osmotic pressure, 156, 157f, 158, 189  
   pH and, 156  
   temperatures and, 154–156, 155f, 156f  
 food production  
   *Aspergillus niger* in citric acid production, 341  
   disinfectants used in, 194  
   endospore-forming bacteria problems in, 97  
   endospores problematic to, 97  
   genetically modified products, 267t  
   inspection agencies, 800  
   microbes used in, 2, 805–807  
 food spoilage  
   acidic foods and, 801  
   bacterial vs. mold damage, 341  
   of canned foods, **800**, 803t  
   flat sour, **800–801**, 803t  
   thermophilic anaerobic, **800**, 803t  
   *Clostridium* bacteria and, 618, 800  
   commercial sterilization to prevent, **182**, 183t, **800–801**, 801f, 802f  
   fermentation and, 8, 133, 134b  
   lactic acid and, 133  
   pasteurization to prevent, **8**, **187–188**, 191t  
   pH and, 156  
   *Pseudomonas* bacteria and, 309  
   refrigeration and, 155f, 188–189, 309, 317, 620  
   relationship between microbes and, 8, 800  
   *Salmonella* bacteria and, 310  
   temperature and, 154–156, 154f–156f  
   thermophilic anaerobic spoilage, **800**, 803t  
 food thickeners  
   algin (from brown algae), 345–346  
   carrageenan (from red algae), 346  
   xanthan (from *Xanthomonas campestris*), 801b  
 food vacuoles  
   of *Amoeba proteus*, 351f  
   *Chilomastix* and, 350f  
   in digestive system of protozoa, 349, 351f  
   of *Paramecium*, 353f  
 foodborne illness  
   *Campylobacter jejuni* and, 313  
   *Clostridium perfringens* and, 314  
   *E. coli* enterotoxins causing, 310  
   epidemics, *E. coli* 0157:H7, 19, 82  
   hemolytic uremic syndrome (HUS), 718  
   hepatitis A virus and, 369  
   incidence in U.S., 717  
   *Listeria monocytogenes* and, 619–621, 620f  
   *Salmonella typhi* and, 311  
   salmonellosis, 311, 715b  
   *Staphylococcus aureus* and, 316, 441t, 717–718, 717f, 728b  
   transmission of disease and, 412f, 413–414, 413t  
 foods  
   freeze-dried, 189  
   microbes used in production of, 245  
 forensic medicine, DNA fingerprinting and, 261, 263f  
 forensic microbiology, 244, **261**, 263  
   criminal convictions and, 261  
   DNA fingerprinting and, 261, 263f  
 forespore, 96f, 97  
 formaldehyde, 197, 202t  
 formalin, 197  
 formic acid, 132f  
 formylmethionine, 216, 276t  
 fossils, 275, 277  
   *Bacillus sphaericus* survived embedded in, 277  
   cladograms and, 293  
   cyanobacteria and atmospheric oxygen, 320–321  
   cyanobacteria-like, 275, 275f  
   DNA studies and, 261, 263  
   oldest known, 275, 277  
   phylogeny and, 275, 275f  
   of prokaryotes, 275, 277, 277f  
   rRNA sequencing and, 293  
 fowl cholera, 312, 507  
 foxes  
   as disease reservoirs, 413t  
   reported cases of rabies in, 630f  
 FQ. See fluoroquinolones  
 fractures, genetically modified therapy for, 259t  
 frameshift mutagens, 227  
   carcinogens and, 227  
 frameshift mutations, **225**, 225f  
*Francisella* genus/spp., 301t, **307**  
*Francisella tularensis*, 307  
   can remain dormant within phagocytes, 462, 643  
   as potential biological weapon, 642, 642f, 654b  
   tularemia caused by, 307, 648, 656b, **656b**  
*Frankia* genus/spp., 302t, 318, **319**  
   actinomycetes informal name for, 318–319  
 Franklin, Rosalind, 47  
 free (extracellular) antigens  
   B cell activation and, 482, 482f  
   in humoral immunity, 482, 482f, 500f  
 free radicals, 201, 227, 259t  
 free ribosomes, 101  
 free (wandering) macrophages, **460**  
 freeze-drying (lyophilization), **168**, 191t  
   desiccation and, 189  
 freeze-thaw cycle, vegetative bacteria and, 189  
 freezing temperatures  
   bacteria and, 189  
   food spoilage and, 155, 155f, 189  
 freshwater microbiota, 2, 301t, 304, 305f, 306, 306f, 309, **782–783**  
 frogs, deformed, 358f  
 fructose, 38, 38f, 144, 144f  
   microbes in manufacture of, 244  
   plasma membrane crossings and, 91, 91f  
   in polysaccharides biosynthesis, 144, 144f  
 fruit flies, *Wolbachia* bacteria and, 308b  
 fruit juices  
   fermentation and, 134t  
   high pressure techniques to preserve, 189  
 fruiting bacteria, 56b, 56f, 313, 313f  
 fruits and vegetables  
   genetically modified MacGregor tomatoes, 267, 267t  
   PAA for washing/disinfecting, 202  
 fruticose lichens, 342, 343f  
 FTA-ABS tests, 61f, **761–762**  
 fuel products  
   deep-sea hydrothermal vents and, 157b  
   fermentation and, 134t  
 fully human antibodies, **514**  
 fulminating disease, 606  
 fumaric acid, 126f, 147f  
 functional groups, **36–37**, 36t  
 fungal blights on trees, 341–342  
 fungal diseases, 331–332. See also fungal infections  
   antifungal drugs to treat, 558  
   of digestive system, 735–736, **740b**  
   of nervous system, **623b**, 632–633, 632f  
   of reproductive systems, 758–759, **759b**  
   of respiratory system, 702–706  
   of skin, 594b, **605–607**, 606f  
 fungal infections (mycoses), 331–332, **339–341**, 340t  
   Clinical Case, 332b, 339b, 341b, 342b  
   cutaneous, **340–341**, 340t, 568, **605–607**, 606f  
   emerging (*Cryptococcus gattii*), 342b  
   increasing rates of, 14  
   opportunistic, **340–341**  
   systemic, **339**  
 fungal zoonoses, 413t  
 fungi-farming ants, 332  
 fungi/fungus, 2, 4, **280**, 330, **331–342**, 331f, 333t



- alcohols effective against, 194–195, 202*t*
- anamorphic, **335**, 341
- anamorphs, **338**
- antibiotics derived from, 12, 12*f*, 247, 560*t*
- antimicrobial drugs that inhibit, 562*t*
- asexual spores and, 331*f*, **334–335**, 335*f*, 336*f*, 340*t*
- bacteria vs., 332, 333*t*, 334
- beneficial activities of, 332, 341
- biofilms and, 161
- as biological controls of pests, 341
- biotechnology uses for, 341
- as carbon recyclers, 15, 332
- cell structure, 4, 5*f*
- cellulases produced by, 38
- characteristics of, 331–335, 331*f*, 332*f*
- as chemoheterotrophs, 141*f*, 143, 331*f*
- chitin in cell wall, 38
- dimorphic, **334**, 334*f*, 340*t*
- as disease reservoirs in soil, 411
- diseases caused by, 339–341, 340*t*
- economic effects of, 341
- emerging infectious diseases caused by, 419*t*
- as eukaryotes, 4, 6, 75, **280**, 330, 331*f*
- filamentous, 320
- fleshy, 331, 331*f*
- human uses of, 332
- identification by microscope, 281
- identification methods for, 331
- iodine active against, 193
- ketoconazole to treat, 562*t*
- as Kingdom in domain Eukarya, 4, 6, 274, 274*f*, **280–281**, 331–342
- lichens and, 342, 343*f*
- life cycle of, 334–335, 336*f*–339*f*
- low-moisture environments, growth and, 332
- medically important, 337–338, 340*t*
- metabolism of, 333*t*, 336
- moist heat sterilization to kill, 185
- mucor*, 5*f*
- mycology as study of, **14**, **332**
- nutritional adaptations, 336
- nutritional classification of, 141, 141*f*
- nutritional requirements, 4
- pathogenic, 331–332, 339–341, 340*t*, 443. *See also* fungal diseases
- penicillin produced by, 12, 12*f*
- Penicillium*, rDNA technology and, 247
- pH ranges tolerated by, 35, 336
- Pneumocystis* classification and, 284
- rapid identification tests for, 285
- reproduction in, 4, 331*f*, 334–335, 335*f*, 336*f*, 337*f*, 338*f*, 339*f*
- aerial hyphae and, 331, 331*f*
- resistance to chemical biocides, 200, 200*f*
- rules for naming and, 278
- silkworm disease and, 11
- skin's keratin no obstacle to, 430
- spores of, 331*f*, 332*f*, **334–335**, 334*f*
- allergic reactions to, 530
- resistance to chemical biocides, 203*f*
- sterols found in, 41
- teleomorphs, **338**
- toxin-producing, 341, 445
- vegetative structures of, 331–335, 331*f*
- Fungi (kingdom), **4**, 6, 273, 274, 274*f*, **280–281**, 331–342, 331*f*
- characteristics of, 331*f*, 332–336
- energy sources of, 281
- lichens and, 342, 343*f*
- medically important, 337–338, 340*t*
- nutritional needs of, 281, 331*f*, 336
- organisms included in, 281
- position in evolutionary tree, 274*f*
- in taxonomic hierarchy, 279*f*
- fungicides, 182, 196
- fungistats, calcium propionate, 197
- fungus. *See* fungi/fungus
- furiose rabies (in animals), **623**
- furuncle (boil), **593**
- Fusarium*, toxin of, 445
- fusiform bacteria, 322, 324*f*
- fusion, in viral multiplication, **385**, 385*t*, 386*f*
- fusion inhibitors, **576–577**
- to treat HIV infection, 548
- Fusobacteria, 302*t*
- Fusobacteriales, 302*t*
- Fusobacterium* genus/spp., 302*t*, **322**, 324*f*
- in gingival crevices, 322
- as normal microbiota of mouth, 404*t*
- G**
- G + C ratios, high, 280*f*, 302*t*, 318–320
- G-CSF (granulocyte-colony stimulating factor), 497
- GAE (granulomatous amebic encephalitis), 623*b*, **635**
- Gajdusek, Carleton, 637
- gal* gene, in specialized transduction, 384, 384*f*
- galactose, 38, 91, 91*f*
- specialized transduction and, 384, 384*f*
- GALT (gut-associated lymphoid tissue), 712
- Gambierdiscus toxicus*, ciguatera disease and, **347**
- gametes (gametocytes)
- in life cycle of *Rhizopus*, 336*f*
- of plasmodial slime mold, 355*f*
- in protozoan conjugation, **349**
- gamma globulin, **498–499**
- gamma interferon, 259*t*, 471
- E. coli* genetically modified to produce, 255–256, 256*f*
- gamma radiation, provirus expression and, 391
- gamma rays, 189, 190*f*
- in food irradiation, 797–798, 798*f*
- as mutagens, 227
- gammaproteobacteria, 279*f*, 301*t*, 303, **307–312**
- important genera/special features, 301*t*
- ganciclovir, 566*t*, 575
- gangrene, 96, **652–653**, 652*f*, **673b**
- Clostridium perfringens* causing, 652–653, 652*f*, 673*b*
- gas, 314, 431*t*, 435, 441*t*, 442*t*, **652–653**
- hyperbaric chamber to treat, 653, 653*f*
- penicillin to treat, 653
- portals of entry, 430, 431*t*
- Gardasil (HPV vaccine), 259*t*, 393, 506*t*, 543, 758
- Gardnerella* genus/spp., 302*t*, **318**, **319**
- Gardnerella vaginalis*, 319, 756, 756*f*
- gas formation
- in carbohydrate catabolism, 136, 137*f*
- by *Streptomyces*, soil odor and, 320
- gas gangrene, 314, 431*t*, 435, 441*t*, 442*t*, **652–653**
- Clostridium perfringens* causing, 314, 431*t*, 441*t*, 652–653
- exotoxin causing, 441*t*, 652
- hyperbaric chambers to treat, **653**, 653*f*
- incubation period, 431*t*
- symptoms, 431*t*, 441*t*
- GAS (group A streptococci), 317, 594–595, 594*f*, 640
- gas vacuoles, **95**, 321
- gas vesicles, 95
- gaseous chemosterilants, 198–199, 202*t*
- gastric juice
- as chemical defense against pathogens, **455**, 474*t*
- pH of, 455
- toxins not destroyed by, 455
- gastritis, *Helicobacter pylori* and, 455
- gastroenteritis, **717**
- Bacillus cereus*, **726–727**, 728*b*
- Campylobacter*, **724**, 728*b*
- Clostridium perfringens*, **726**, 728*t*
- Escherichia coli*, **723–724**, 723*f*, 728*b*
- traveler's diarrhea, **724**, 728*b*
- genomics used to track outbreak, 261, 265*b*
- hepatitis E virus and, 377*t*
- norovirus-associated, 261, 265*b*, **728–729**, 729*b*
- recreational water-associated outbreaks, 357*b*
- rotavirus-associated, **728**, 729*b*
- Salmonella*, 310–311, 413*t*, **719–720**, 719*f*, 720*f*, **728b**
- Vibrio parahaemolyticus* and, 310, 723
- viral, **734–735**, **736b**
- Yersinia*, **726**, **728b**
- gastrointestinal anthrax, 432, **651–652**, 655*b*
- gastrointestinal (GI) tract, 452, **712**.
- See also* digestive system
- parasitic helminths and, 364*t*
- as portal of entry, 430, 431*t*, 432, **447f**
- as portal of exit, 446
- gatifloxacin, 565*t*, 572
- gauze, quat antiseptics neutralized by, 197
- GB virus, 728
- GBS (group B streptococci), 317, 320*b*, 324*b*, **647**
- neonatal sepsis caused by, 317, 320*b*, 324*b*, **647**
- gel electrophoresis, **261**
- pulsed-field (PGE), 718
- to separate serum proteins, 498, 498*f*
- in Southern blotting, 261, 262*f*
- to view amplified DNA, 251, 290
- gemifloxacin, 572
- Gemmata* genus/spp., 302*t*, **322**, 324*f*
- nucleus and, 275, 302*t*, 322, 324*f*
- Gemmata obscuriglobus*, eukaryotic nucleus and, 322, 324*f*
- GenBank, 261
- gender, as predisposing factor, 410
- gene-cloning vectors/cloning vectors, 245, 246*f*, 248–249, 249*f*
- gene expression, 208, 210*f*, 218–223. *See also* transcription; translation
- enzymes important in, 210, 211*t*
- regulation of, 218–223
- epigenetic inheritance and, 222
- induction, **219**, 221*f*
- operon model, 219–221, 221*f*, 222*f*
- positive regulation, 221–222, 222*f*
- repression, **219**, 222*f*
- silencing of, 258
- gene gun, 251–252, 252*f*
- to inject vaccines, 508
- gene library. *See* genomic library
- gene mapping
- bioinformatics and, 261
- by conjugation, 234
- of *E. coli* chromosome, 209*f*
- Human Genome Project and, 260
- Human Proteome project and, 260
- proteomics and, 261
- of resistance plasmid R100, 236, 238*f*
- gene silencing, **258**, 258*f*
- as natural process occurring in organisms, 258
- reverse genetics and, 261
- gene therapy, **16**, **258**
- viral DNA and, 249
- viral DNA as vectors, 249, 258
- gene transfers
- in bacteria vs. in plants/animals, 232
- by conjugation, **234**, 235*f*
- by crossing over, **231**, 231*f*
- horizontal, 213*f*, **232**, 275, 583*b*
- by transduction, **234**, 237*f*
- transformation and, **232–233**, 233*f*, 234*f*
- by transposition (transposons), 237, 238*f*, 239
- vertical, 213*f*, **232**
- Genencor, **3b**
- genera. *See* Genus/genera
- generalized infection (systemic infection), **409**
- generalized transduction in bacteria, **234–235**, 237*f*
- generation time, **168–169**, 169*f*
- genes, 15, 44, **208**. *See also* DNA
- antibiotic-resistant, in intestinal microbiota, 405
- antibody diversity and, 482*f*, 487
- antigen recognition requirements and, 487
- artificial, 253–254, 254*f*

- cancer-inducing, viruses and, 393–394  
 chemically synthesized, 254  
 cloning and, 245, 246f, 255–257, 256f  
 eukaryotic  
   cDNA method for obtaining, 253, 254f  
   transcription and, 215, 218, 219f  
 evolution and, 239  
 expression of, **208**. *See also* gene expression  
 genetic transfers/transformation. *See* genetic transformation  
 inducible, 219–221, 221f  
 libraries of, 253, 253f  
 minimum necessary for free-living existence, 318, 326  
 mutation and, 223–231  
 mutation rates, 231  
 in plasmids, 94  
 as products, 255–257, 256f. *See also* genetic modification  
 prokaryotic  
   in chromosome of *E. coli*, 209f  
   in protein synthesis, 215–218, 216–217f, 218f  
   transcription, 214f, **215**, 218  
 repressible, 219–221, 222f  
 sources for rDNA products, 252–254, 253f  
 structural, 220–221, 221f, 222f  
 synthetic, 253–254, 254f  
 genetic change, plasmids/transposons as mechanisms of, 235–237, 239  
 genetic code, **208**, 215, 215f  
   amino acids in proteins and, 42t, 215f  
   degeneracy and, 216, 224, 254  
 genetic counseling, ethical issues, 261, 267  
 genetic diseases  
   familial disorders and, 395  
   gene therapy and, 16, **259**  
   testing/screening for, 261  
 genetic diversity, 231, 239  
 evolution and, 239  
 genetic engineering. *See* genetic modification  
 genetic information  
   flow of from one generation to next, 209, 210f  
   location in bacterial cell, 79f, 94  
   transcription of, 214f, **215**, 218  
   translation of, **215**–218, 216–217f, 218  
   of viruses, classification and, 394b  
 genetic material  
   changes in (mutation), 223–231  
   chemicals that damage (genotoxins), 232b  
   DNA and chromosomes, 209, 209f  
   DNA replication processes, 210–215, 211f–214f  
   genotype and, 208–209  
   information flow and, 209, 210f  
   phenotype and, 208–209  
   protein synthesis and, 215–218, 216–217f  
   recombination processes, 231–239.  
     *See also* genetic recombination  
   RNA and protein synthesis, 215–218, 216–217f  
   structure/function of, 208–218  
 genetic modification, **245**. *See also* recombinant DNA (rDNA)  
   technology  
     of agricultural products, 263–264, 266, 267t  
     of animal husbandry products, 266, 267t  
     of food production products, 267t  
     of pharmaceutical products, 258–259, 259t  
   techniques, 251–257  
     clone selection, 255, 255f  
     complementary DNA (cDNA), 252–253, 254f  
     electroporation, **251**  
     gene gun, 251–252, 252f  
     genomic libraries, 253, 253f  
     inserting foreign DNA into cells, 251–252, 252f, 263–264, 264f  
     making a gene product, 255–257, 256f  
     microinjection, **252**, 253f  
     obtaining DNA for, 252–254  
     protoplast fusion, **251**, 252f  
     synthetic DNA, 253–254  
     transformation, **251**. *See also* transformation  
     typical procedure, 246f  
   therapeutic products, 258–259, 259t  
   transgenic animals, 258, 259t, 267t  
 genetic recombination, **231**–239.  
   *See also* recombinant DNA (rDNA) technology  
   avian influenza (H5N1) and, 418, 693  
   beneficial aspects of, 231  
   conjugation, 234, 235f  
   by crossing over, **231**–232, 231f  
   *E. coli* O157:H7 and, 418  
   emerging infectious diseases and, 418  
   by gene transfers, 231–232  
   naturally occurring, 233  
   plasmids, 235–237, 238f  
   reassortment and antigenic shifts of flu virus, 693  
   transduction, 234–235, 237f  
   transformation and, 232–233, 233f, 234f, **251**  
   transposons, 237, 238f, 239  
 genetic testing/screening, **261**, 267  
 genetic transformation, **232**–233, 233f, 234f, **251**  
 genetically modified plants, 257, 263–264, 264f, 266, 267t  
 genetics, **208**  
   genetics, microbial, **15**, 207–243  
     evolution and, 239  
     flow of information in 209, 210f  
     gene expression, 218–223  
     genetic material's structure/function, 208–218  
     genetic transfer/recombination, 231–239  
     mutations, 223–231  
 genital herpes (herpes simplex virus type 2/HSV-2), **763**, 763f, 764f, **767b**  
   acyclovir to treat, 570f, 575, 764  
   alpha interferon to treat, 473  
   incidence, 567f, 763f  
   latent state in nerve cells, 764  
 genital infections  
   *Chlamydia trachomatis* and, 424t  
   *Trichomonas vaginalis* and, 349, 350f  
 genital warts, 430, **764**–765, 765f, **767b**  
   human papillomavirus causing, 377t, 387  
   imiquimod to treat, 575  
   vaccines and, 765  
 genitourinary tract  
   as portal of entry, 430, 431t, **447f**  
   as portal of exit, 446–447  
 genome, **208**  
   of flavivirus, 220b  
   libraries, 252–253, 253f  
   minimum genetic requirements, 318, 327  
   projects, 260, 261  
   sequencing and, 260, 260f, 261  
   short tandem repeats (STRs) and, **209**, 260  
   viral, 261, 393, 394b  
 genomic libraries, 252–253, 253f  
 genomics, **14**, **209**  
   GenBank, 261  
   infectious diseases and, 261  
   as mainstay of infectious disease monitoring, 261  
   metagenomics and, 260  
   in norovirus tracking, 261, 265b  
   projects, 260, 261  
   in West Nile virus tracking, 209, 220b, 220f  
 genotoxic chemicals, 231b, 232b  
   Ames test and, 230–231, 230f, 231b, 232b  
 genotype, **208**–209  
   changes in, 223–224. *See also* mutations  
   ways bacteria acquire new, 235  
 gentamicin, 559b, 565t, 570, 570b  
 broth dilution assay, 579b  
 corneal transplants and, 559b, 570b, 579b, 581b, 584b, 585b  
   produced by *Micromonospora purpurea*, 560t, 565  
   protein synthesis inhibited by, 94, 562t, 564t, 570  
 genus/genera (taxonomic), defined, **3**, **278**, 279f  
*Geobacillus stearothermophilus*, causing food spoilage, 795, 796t  
 geosmin, gas produced by *Streptomyces*, 320  
 germ theory of disease, 8–9, 11, 406–408, 479  
 Germ-X hand sanitizer, 195  
 German measles. *See* rubella  
 germfree mammals, without normal microbiota, research and, 403  
 germicidal (UV) lamps, 190, 191t  
 germicides, **182**  
 germination, **97**  
 germs, 2. *See also* microbes/microorganisms  
 Gerstmann-Sträussler-Scheinker syndrome, 395  
 giant bacteria  
   *Epulopiscium*, 301t, **314**–315, 315f, 326  
   *Thiomargarita namibiensis*, 301t, 326  
 giant clam (*Tridacna*), symbiotic host to dinoflagellate algae, 348  
*Giardia*, 349, 350f  
   antigenic variation and, 446  
   lack of mitochondria in, 103, 349  
   parasitic species, 349, 350f, 356t  
   pathogenic mechanisms of, 446  
*Giardia duodenalis*, 349, 350f  
*Giardia intestinalis*, 349, 350f  
*Giardia lamblia*, 349, 350f, 356t, 736–737, 740b  
   pathogenic mechanisms of, 446  
 giardial enteritis, 356t  
 giardiasis, 349, **736**–737, 737f, **740b**  
   metronidazole to treat, 571, 737  
   as notifiable infectious disease, 424t  
   portal of entry, 431  
   quinacrine to treat, 577, 737  
 gingival bacteria  
   *Bacteroides*, 322  
   *Fusobacterium*, 322, 324f  
 gingivitis, **715**, 716b  
 gliding motility, **83**, 301t  
   of cyanobacteria, 321  
   of *Cytophaga*, 322  
   of *Myxococcus*, 313, 313f  
 global warming, **776**  
   emerging infectious diseases, 418  
 globular proteins  
   enzymes as, 113  
   flagellin, 81  
   shape/structure of, 44, 45f  
 globulin proteins, antibodies as, 479  
*Gloeocapsa* genus/spp., 302t, 321f  
 glomerulonephritis, **535**  
*Glossina* (tsetse fly), African trypanosomiasis transmitted by, 356t, 364t, 413t, 633, 638b  
 glucans, 99, 333t  
*Gluconacetobacter xylinus*, 3b  
*Gluconobacter* genus/spp., 3b, 134t, 300t, **304**, 800  
 glucose  
   ATP yield, in eukaryotes/prokaryotes, 130t, 131f, 132f, 133f, 135t  
   in Calvin-Benson cycle, 140f  
   in chemically defined media, 162, 162t  
   in dehydration synthesis, 38f  
   *E. coli* lactose metabolism and, 219–221, 221f, 223f  
   as an energy source, 37, 38f, 120, 139, 141f  
   fermentation and, 130, 133f  
   in genetic control mechanisms and, 219–221, 221f  
   glycolysis and, 122, 123, 123f, 124f, 125  
   in hydrolysis, 38f  
   in lipids biosynthesis, 144, 145f

- in nucleotide biosynthesis, 145–146, 146f  
 oxidation of, 120, 123, 123f, 124f, 125, 125f  
 plasma membrane crossings and, 91, 91f, 93  
 in polysaccharides synthesis, 144, 144f  
 synthesis of, 144  
 transport by group translocation, 93
- glucose 6-phosphate  
 enzyme specificity and, 118  
 in glycogen synthesis, 144, 144f  
 in nucleotide synthesis, 145–146, 146f
- glucose effect (catabolite repression), 222
- glucose-phosphate isomerase, 115t
- glucosyltransferase, produced by *Streptococcus mutans*, 432
- glutamic acid (Glu)  
 structural formula/characteristic R group, 42t  
 in transamination, 145f
- glutamine (Gln)  
 in biosynthesis of nucleotides, 146f  
 structural formula/characteristic R group, 42t
- glutaraldehyde (Cidex), 197, 198, 201t, 202t
- glyceraldehyde 3-phosphate (GP), 124  
 in biosynthesis of lipids, 147f  
 in Calvin-Benson cycle, 140f  
 in lipid catabolism, 135f
- glycerol, 39–40, 39f, 89  
 in fat molecule formation, 39, 39f  
 as fermentation end-product, 134t  
 in lipid catabolism, 134, 135f, 136f  
 in lipids biosynthesis, 144, 145f
- glycine (Gly), structural formula/characteristic R group, 42t
- glycocalyx  
 eukaryotic cell, 98f, 99–100, 100t  
 prokaryotic cell, 75, 79f, 80  
 as slime layer, 80, 97b
- glycogen, 38  
 synthesis of, 144, 144f
- glycogen granules, in presence of iodine, 95
- glycolipids, 90
- glycolysis, 122–125, 123f, 124f  
 alternatives to, 123, 125  
 ATP yield and, 124, 130t  
 fermentation and, 123f, 130–133, 133f  
 in lipid catabolism, 136f  
 in nucleotide biosynthesis, 145–146, 146f  
 in synthesis of new cell components, 144–146, 144f–147f
- glycoproteins, 44, 90  
 as adhesins (ligands) of pathogens, 432
- glycylalanine, 44f
- glycylclines, 571t
- glyphosate (herbicide)  
 insecticidal toxin (Bt toxin) and, 264  
 resistance and, 264, 267t
- goblet cells, of ciliary escalator, 454f
- gold  
 used in staining of specimens, 62  
 used with gene guns, 252, 252f
- Golgi complex, 98f, 102–103, 104f
- gonorrhea, 307, 754–756. *See also* *Neisseria gonorrhoeae*  
 antibiotic resistance and, 756, 756b  
 antigenic variation and, 435, 756  
 arthritis as complication of, 755  
*Chlamydia trachomatis* and, 756  
 desiccation and bacterium causing, 189  
 diagnosis of, 756, 756f  
 endocarditis as complication of, 755  
 as epidemic disease, 406, 755f  
 incidence and distribution, 754, 755f  
 incubation period, 431t, 754–755  
 meningitis as complication, 755  
 as notifiable infectious disease, 424t  
 ophthalmia neonatorum and, 195, 202t, 430, 603–604, 609b, 755–756  
 pelvic inflammatory disease and, 755  
 portals of entry, 430, 431t, 754  
 pregnancy and, 755–756  
 tetracyclines to treat, 565, 756
- GP (glyceraldehyde 3-phosphate), 122
- gp120 spikes of HIV, 545, 546f, 553
- Gracilaria*, 346
- graft-versus-host (GVH) disease, 497, 541, 544b
- grafts, 540–541
- Graham sticky-tape method, 358
- grains  
 aflatoxin and, 227  
 ergot toxin and, 445  
 fermentation and, 134t  
 molds and spoilage of, 189, 230
- Gram, Hans Christian, 10f, 68
- gram-negative archaea, 302t
- gram-negative bacteria, 68f, 69, 300–301t, 303–314  
 antimicrobial drugs that inhibit, 562t  
 cell walls, 84, 85f, 86  
 Gram stain mechanism and, 86, 87t  
 hypotonic solutions and, 93  
 characteristics of, 87t, 202  
 colonizing water pipes, laboratory containers, 440b, 440f  
 conjugation in, 234  
 cytotoxicity susceptibility and, 467  
 disinfectants effective against, 196, 196f  
 endotoxic shock caused by, 440  
 Entner-Doudoroff pathway and, 125  
 fimbriae of, 82–83, 83f  
 flagella of, 81, 81f  
 lipid A and, 86  
 lipopolysaccharide (LPS) of, 69, 85f, 86, 440, 452  
 nonproteobacteria genera, 302t, 320–322, 321f, 321t  
 nosocomial infections and, 415, 416t  
 proteobacteria genera as, 300–301t, 303–314. *See also* proteobacteria
- resistance to chemical biocides, 200, 200f  
 vs. gram-positive bacteria, 69, 81, 86, 87t
- gram-negative shock (endotoxic shock), 440, 646
- gram-positive archaea, 302t
- gram-positive bacteria, 68f, 69, 301–302t, 314–320  
 actinobacteria, 302t, 318–320  
 antibiotics derived from, 560t  
 antimicrobial drugs that inhibit, 562t  
 cell walls, 84, 85f  
 Gram stain mechanism and, 86, 87t  
 characteristics of, 87t  
 conjugation in, 234  
 cytotoxicity resistance and, 467  
 disinfectants effective against, 196, 196f  
 endospores and, 95–97, 96f  
 firmicutes, 301t, 314–318  
 flagella of, 81, 81f  
 high G + C ratio, 280f, 302t, 318–320  
 low G + C ratio, 280f, 301t, 314–320  
 nosocomial infections and, 415, 416t  
 phylogenetic relationships, 280f  
 position in evolutionary tree, 274f  
 resistance to chemical biocides, 200, 200f  
 resistance to physical disruption, 87t  
 vs. gram-negative bacteria, 69, 81, 86, 87t
- gram-positive sepsis, 646–647
- Gram stain, 68–69, 68f, 71t, 86, 87t  
 Archaea and, 87  
 bacteria (gram-negative vs. gram-positive) reaction to, 87t  
 stool sample, 273b, 286b, 287b
- gram-variable bacteria, 86
- granddaughter DNA, altered, 223–224, 224f, 226f
- granules  
 metachromatic, 95  
 polysaccharide, 95
- granulocyte-colony stimulating factor (G-CSF), 497
- granulocytes, 456
- granulomas, of schistosomiasis, 674, 675f
- granulomatous amebic encephalitis (GAE), 623b, 635  
 caused by *Acanthamoeba*, 623b, 635  
 caused by *Balamuthia*, 351, 356t, 623b, 629
- granulomatous disease, chronic, 259t
- granum/grana, 103, 105f
- granzymes, 458, 493
- grapes, fermentation and, 134t
- graphs, microbial death curve, 183, 184f
- grappling hook model of twitching motility, 83
- grasshoppers, protozoa *Nosema locustae* as insecticide against, 348
- Graves' disease, 537
- HLA typing to determine susceptibility, 539t
- Grays, as radiation measurement, 796
- Great Salt Lake, extreme halophiles (archaea) found in, 326
- green algae, 345f, 345t, 346  
 terrestrial plants may have arisen from, 346
- green bacteria, 141, 141f, 142, 143t
- green monkey virus. *See* Marburg virus
- green monkeys, AIDS and, 379
- green nonsulfur bacteria, 141f, 143, 143t, 321t, 323, 324  
 phylogenetic relationships, 280f
- green photosynthetic bacteria, 302t
- green plants, as photoautotrophs, 141–143, 141f
- green scum in ponds, formed by filamentous green algae, 343
- green sulfur bacteria, 143, 321t, 323, 324, 777  
 characteristics, compared, 321t  
*chlorobium vesicles* of, 143  
 phylogenetic relationships, 280f  
 Griffith, Frederick, 10f, 232–233, 233f  
 griseofulvin, 566t, 575, 606  
 produced by *Penicillium griseofulvum*, 560t, 569
- group A streptococci (GAS), 317, 594–596, 595f, 640, 683
- group B streptococci (GBS), 317, 320b, 324b, 647  
 neonatal sepsis caused by, 317, 320b, 324b, 647
- group translocation, 93, 100
- growth (human), childhood  
 deficiencies, human growth hormone to treat, 259t
- growth (microbial), 153–180. *See also* control of microbial growth  
 carbon requirements, 158  
 Clinical Case, 154b, 166b, 175b, 177b  
 in cultures, 168–177  
 cell division and, 153, 168–169, 169f  
 direct measurements, 171–175  
 estimating numbers, 175–177  
 generation time, 168–169, 169f  
 growth curves, 169f, 170–171, 170f  
 logarithmic representations, 169–171  
 measurement methods, 153, 171–177, 172f–177f  
 media for, 153, 161–166  
 phases of growth, 170–171, 170f  
 nitrogen requirements, 158  
 osmotic pressure and, 156, 157f, 158  
 oxygen requirements, 158–160, 159t  
 pH and, 156  
 phases of, 153, 170–171, 170f  
 phosphorus requirements, 158  
 in prokaryotic cell/eukaryotic cell/eukaryotic organelles, 276t  
 refrigeration and, 155–156, 155f, 156f  
 requirements for  
 chemical, 153, 158–160, 159t  
 physical, 154–158  
 salt concentration and, 158  
 sulfur requirements, 158  
 temperature and, 154–156, 154f–156f  
 trace elements required for, 158



- GTP (guanosine triphosphate), 126, 126f
- guanine (G), 46f, 47, 208
- in DNA replication, 210–215, 211f–214f
- in transcription, 214f, 215
- in translation, 215–218, 216–217f
- guanosine triphosphate (GTP), 126, 126f
- guinea pigs, culturing viruses in, 379, 406
- guinea worm (*Dracunculus medinensis*) infection, 14, 14f
- Gulf oil spill (2010), bioremediation and, 16, 781
- gummas, 760f, 761
- gummatous syphilis, 760f, 761
- gut-associated lymphoid tissue (GALT), 712
- GVH (graft-versus-host) disease, 492, 541, 544b
- Gymnodinium breve* (dinoflagellate), neurotoxin (saxitoxins) produced by, 344
- gypsy moths, *Entomophaga* to control, 341
- gyrase (DNA), 210, 211t
- H**
- H antigen, 82
- E. coli*, 82
- H1N1 influenza virus, 18, 374–375b, 405f, 447f, 700–701, 700t
- real-time PCR to identify, 290
- H1N2 influenza virus, 374–375b, 700, 700t
- H2N2 influenza virus, 374t, 700, 700t
- H3N2 influenza virus, 374–375b, 700, 700t
- H5N1 influenza, 374–375b, 700
- H7N1 influenza, 374b
- HA (hemagglutinin) proteins
- spikes of influenzavirus, 692–693, 692f
- subtypes of influenza A viruses, 374–375b
- HAART (highly active antiretroviral therapy), 553, 575
- habitats, of pathogenic fungi, 340t
- HACCP (Hazard Analysis and Critical Control Point) system, 800
- Haeckel, Ernst, 273
- HaeIII* restriction enzyme, 248t
- Haemophilus aegyptius*, in rDNA technology, 248t
- Haemophilus ducreyi*, chancroid caused by, 312, 762, 767b
- Haemophilus* genus/spp., 301t, 312
- blood required to culture, 312
- genetic transformation naturally occurring in, 233
- as normal microbiota of mouth, 404t
- nosocomial infections and, 416t
- Haemophilus influenzae*, 5f, 312
- complement system evasion by, 470
- conjunctivitis and, 609
- genome has been sequenced, 260
- HindIII* restriction enzyme used in rDNA technology, 248t
- meningitis and, 312, 433, 612, 613, 623b
- as normal microbiota of throat, 404t
- as notifiable infectious disease, 424t
- otitis media caused by, 312, 685
- phagocytes and, 433
- type b
- evasion of phagocytosis and, 462
- meningitis caused by, 433, 618, 623b
- septic shock and, 439
- vaccine, 506t, 507t, 508, 618
- virulence and capsule of, 433
- Haemophilus influenzae* pneumonia, 312, 433, 613, 693, 695b
- HAI. See health care-associated infections
- hair
- cutaneous mycoses and, 340, 340t
- sebum and, 455
- hair follicles, 590, 590f
- hairs, of nasal mucous membrane, 454, 474t
- hairly leukoplakia, in AIDS patients, 550t
- half-life, of injected antibodies, 495
- Haloarcula* genus, 78, 78f
- Halobacteriales, 302t
- Halobacterium* genus/spp., 95, 302t, 326
- Halococcus* genus/spp., 302t, 326
- halogens
- chlorine, 193–194, 202t
- iodine, 193–194, 201t, 202t
- halophiles, extreme, 4, 158, 274, 274f, 280f, 326
- facultative, 158
- obligate, 158
- halophilic archaea, 78
- hamsters, tularemia and, 656b
- hand sanitizers, 195, 196, 735
- handwashing
- effective technique for, 195
- as most important infection control measure, 417
- Hansen's disease. See leprosy
- Hantavirus*, 378t
- as a biological weapon, 654b
- PCR to identify, 290
- reservoirs/transmission method, 413t
- Hantavirus* pulmonary syndrome, 378t, 413t, 666, 667b
- emerging infectious diseases and, 418, 419t
- global warming and, 418
- as notifiable infectious disease, 424t
- reservoirs/transmission due to, 413t
- haptens, 481, 481f
- allergic contact dermatitis and, 530
- Hartmut, Michel, 10f
- Haverhill fever, 655
- hay fever, 528, 528t, 530
- IgA antibodies and, 484–485
- Hazard Analysis and Critical Control Point (HACCP) system, 800
- HDCV (human diploid cell vaccine) for rabies, 629
- HDNB (hemolytic disease of newborn), 533, 533f
- head lice, ivermectin effective against, 572
- health care-associated infections (HAI), 401, 415
- Acinetobacter baumannii* and, 309
- Clostridium difficile* and, 401
- compromised hosts and, 416, 417t
- cost of, 582
- hospitals and, 414–417, 415f. See also nosocomial infections
- infection following steroid injection, 198b
- MRSA and. See MRSA
- norovirus outbreak and, 182b, 197b, 199b, 201b
- pseudomonads responsible for one in ten, 309
- rates of, 415, 416t, 417t
- schools and, 182b, 197b, 199b, 201b
- treatments in, resulting in compromised hosts, 416
- health care facilities, infections. See nosocomial infections
- health care personnel
- antibiotic resistance and, 576
- hospital-acquired infections and. See nosocomial infections
- Universal Precautions for (CDC), 546t
- hearing loss, caused by aminoglycoside antibiotics, 565
- heart, 644, 644f, 649b
- endocarditis, 647
- acute, 648, 649b
- subacute, 647–648, 647f, 649b
- pericarditis, 648
- rheumatic fever, 317, 648, 649b
- heart attacks
- genetically modified products to treat, 259t
- streptokinase to treat, 434b
- heart transplant patients, impaired innate defenses of, 465
- heart valves
- abnormal, endocarditis risks and, 647
- biofilms colonizing, 161, 433, 647, 647f
- as privileged tissue, 535
- rheumatic fever and, 648, 649b
- heartworm (*Dirofilaria immitis*), 361–362, 362f, 364t
- Aedes* mosquito as vector, 362, 364t
- Wolbachia* bacteria essential to, 362
- heat
- anabolic/catabolic reaction and release of, 112–113, 112f
- high-heat cooking, amines that form, 231b
- of inflammation, 460
- lost in energy production, 144
- reaction rates and, 113
- stains/staining and, 67, 69, 71
- heat-labile enterotoxins, 440
- produced by *E. coli* strains, 439
- heat-loving microbes (thermophiles), 154, 154f
- endospores of, 97
- heat-resistant (thermoduric) bacteria, pasteurization and, 187
- heat treatments in microbial control, 185–188, 191t
- dry heat, 188
- enzyme denaturation and, 185, 191t
- equivalent treatments and, 188
- factors influencing effectiveness, 183
- flaming, 188
- hot-air, 188
- mechanism of action, 185, 188
- moist heat, 185–187
- pasteurization, 187–188
- to remove *Clostridium botulinum* endospores, 182, 183t
- resistance to, 185
- summary (method/mechanism of action/uses), 191t
- heavy chains of antibodies, 482, 482f, 483t
- heavy metals
- as disinfectants, 195–196, 195f, 202t
- gram-negative bacteria and, 87
- R factors that confer resistance to, 236
- used in staining of specimens, 62
- HeLa cell line, 380
- helical virus, 373, 373f
- helical viruses, 373, 373f
- enveloped, 373, 373f
- helicase, 210, 211t
- helices of protein structure, 44, 45f
- Helicobacter* genus/spp., 301t, 313, 314f
- Helicobacter pylori*, 53f, 313, 314f
- Clinical Case, 54b, 64b, 69b, 71b
- peptic ulcer disease, 54b, 64b, 313, 314f, 725–726, 725f
- stomach acid and, 455
- helium, used with gene guns, 252, 252f
- helminthic diseases
- of cardiovascular/lymphatic systems, 673–675
- of digestive system, 738–744
- helminthic zoonoses, 413t
- helminths, 6, 331f, 354–363, 355, 364t
- antimicrobial drugs that inhibit, 562t
- emerging infectious diseases caused by, 419t
- parasitic, 330, 354–363, 364t
- characteristics of, 355–356
- habitat, 354–355
- life cycle, 356
- reproduction in, 356
- pathogenic mechanisms of, 446
- helper T cells. See T helper cells
- hemagglutination, 371, 517
- spikes, influenza viruses and, 371, 373f
- viral, 517, 517f
- hemagglutinin (HA) proteins, 371
- influenza A virus subtypes and, 374–375b
- Influenzavirus* and, 692–693, 692f
- hematologic disorders, sickle cell disease, 225
- hematopoietic cytokines, 497
- hematopoietic stem cells (HSCs), 540
- bone marrow transplants and, 541

- Hemiascomycetes, in taxonomic hierarchy, 279f
- hemodialysis
- antibiotic resistance developing from, 423b
  - disinfectants used in, 194
  - patients at risk for gram-positive sepsis, 640
- hemoflagellates (blood parasites), 330, 350, 667f, 668b
- hemoglobin, 436, 473
- hemolysins, 439, 473, 594
- hemolysis
- in complement testing, 472b
  - gas gangrene and, 441t
- hemolytic anemia, 534
- hemolytic disease of newborn (HDNB), 533, 533f
- hemolytic streptococci, 317, 589–590
- hemolytic uremic syndrome (HUS) *E. coli* O157:H7 and, 724
- as notifiable infectious disease, 424t
- hemophilia, 16
- hemophilia B, gene therapy to treat, 258
- hemorrhagic colitis, 724
- hemorrhagic fever viruses, 19, 290, 378t, 665–666, 667b
- emerging, 637, 666, 667b
  - as potential biological weapon, 654b
- hemorrhagic fever with renal syndrome (*Hantavirus* pulmonary syndrome), 666
- Hendra virus, emerging infectious diseases and, 419t
- HEPA (high-efficiency particulate air) filters, 164, 188
- Hepadnaviridae, 377t, 387–388, 388t, 390b
- biosynthesis of, 388t
  - as DNA virus, 388t
  - as an oncogenic virus, 393
  - synthesize DNA using reverse transcriptase, 388
- Hepadnavirus*
- hepatitis B and, 377t, 387, 431t
  - hepatitis D and, 378t
  - incubation period, 431t
  - portals of entry, 431t
- heparin IV solutions, *P. fluorescens* (Clinical Case), 154b, 166b, 175b, 177b
- hepatitis, 729–734
- alpha interferon to treat, 259t, 575
  - antisense DNA explored as gene therapy, 258
  - blood banking supplies and, 727b
  - Clinical Case, 370b, 390b, 392b, 393b, 394b
  - as emerging infectious disease, 419t
- hepatitis A, 729, 731b
- Clinical Case, 370b, 390b, 392b, 393b, 394b
  - incubation period, 431t
  - as notifiable infectious disease, 424t
- hepatitis A virus (HAV), 369, 377t, 409, 729, 731b
- immunoglobulin, 394b, 729
  - incubation period, 729, 731b
  - portals of entry, 430, 431t, 729
  - as RNA virus, 387, 729
  - transmission route, 392b, 393b, 729
- vaccine, 394b, 506t, 507t, 729
- hepatitis B, 729–732, 730f, 731b
- acute, 730
  - adefovir dipivoxil (Hepsera) to treat, 575, 732
  - alpha interferon to treat, 473, 732
  - chronic, 409, 730–732
  - contaminated needles and, 447
  - incubation period, 431t, 731b
  - lamivudine to treat, 575
  - as notifiable infectious disease, 424t
  - portals of entry, 431t
  - pregnancy and, 760
  - treatments for, 732
  - vaccine, 14, 245, 257, 259t, 341, 506t, 507t, 543, 732
- hepatitis B virus (HBV), 369, 729–732, 730f, 731b
- as cancer-causing virus, 393
  - gene silencing and, 258, 259f
  - Hepadnaviridae and, 387
  - Hepadnavirus*, 377t, 387, 431t
  - incubation period, 431b, 431t
  - portals of entry, 431t
  - transmission route, 392b, 447, 729–730
- hepatitis C, 419t, 731b, 732–733, 733b
- alpha interferon to treat, 473
  - blood bank supply and, 733b
  - as notifiable infectious disease, 424t
- hepatitis C virus (HCV), 369, 377t, 419t, 731b, 732–733
- as RNA virus, 387
- hepatitis D (delta hepatitis), 378t, 731b, 733
- dependent on coinfection with *hepadnavirus*, 378t
  - as RNA virus, 387
- hepatitis E, 419t, 731b, 734
- hepatitis E virus (HEV), 377t, 419t, 727–729, 731b
- as RNA virus, 387
- hepatitis F virus (HFV), 734
- as RNA virus, 387
- hepatitis G virus (HGV), 734
- as RNA virus, 387
- hepatotoxins, 438
- Hepsera (adefovir dipivoxil), 566t, 575
- heptoses, 37
- HER2 gene, 261
- herbicide resistance, genetically modified crop plants and, 264, 267t
- herbicides
- decomposition rate of Agent Orange, 775, 775f
  - glyphosate resistance and, 264, 266
  - RoundUp (glyphosate), 264, 267t
- Herceptin (trastuzumab), 261, 514, 543
- herd immunity, 409, 505, 598, 612
- hereditary traits, determination of, 15, 47
- heredity, science of. *See* genetics
- heredity. *See* genetics
- hermaphroditic helminths, 356
- herpes encephalitis, 603
- herpes gladiatorum, 603
- herpes simplex, 596b, 603
- herpes simplex viruses
- AIDS-associated, 550t
  - latent infections and, 394, 396t
  - neonatal herpes and, 764
  - portals of entry/incubation period, 431t
  - pregnancy and, 764
  - skin rash and, 447, 596b, 603
  - type 1 (HSV-1), 387, 388f, 596b, 603, 603f, 757
  - type 2 (HSV-2), 387, 603, 763, 763f, 767b
- herpes-zoster (shingles), 377t, 394, 396t, 409, 596b, 601–602
- as a latent varicella-zoster virus disease, 409, 596
  - in HIV/AIDS patients, 549, 550t
  - rash caused by, 394, 596b, 602f
  - vaccine, 506f, 602
- Herpesviridae, 377t, 387, 388f, 388t
- biosynthesis in, 386–387, 388t
  - as DNA virus, 387
  - as an oncogenic virus, 393
  - vaccine, 503t
- herpesviruses (HHV), 387, 388f. *See also* HHV-1 to HHV-8
- acridine dyes and, 227
  - acyclovir to treat, 569, 570f
  - biosynthesis in, 386, 388f, 388t
  - cancer, contaminated red bone marrow transplant and, 406, 408
  - incubation period, 431t
  - latent infections and, 394, 394f, 396t
  - portals of entry, 430, 431t
  - species (HHV-1 to HHV-8), 387
  - used to insert corrective genes into human cells, 249
- herpetic keratitis, 605
- herpetic whitlow, 603
- Hershey, Alfred D., 10f
- Hershko, Avram, 13t
- heterocysts, 321, 321f, 778
- heterofermentative (heterolactic) microbes, 133
- heterolactic (heterofermentative) microbes, 133
- heterotrophs (organotrophs), 140–141, 141f, 144
- complex medium for growing, 163t
- hexachlorophene, 192, 193f
- hexose monophosphate shunt. *See* pentose phosphate pathway
- hexoses, 37
- Hfr cell (high frequency of recombination), 234, 236f, 238f
- HGA (human granulocytic anaplasmosis), 290, 424t, 654b, 656b
- hGH (human growth hormone), produced by genetically modified *E. coli*, 247, 259t
- HHV-1 *simplexvirus*, 387, 596b, 603, 603f, 757
- HHV-2 *simplexvirus*, 387, 596b, 603, 757, 757f, 761b
- HHV-3 *Varicellovirus*, 385, 596b, 601. *See also* varicella-zoster virus
- HHV-4 (*Lymphocryptovirus*/Epstein-Barr virus), 377t, 662. *See also* *Lymphocryptovirus*
- HHV-5 (*Cytomegalovirus*), 664
- HHV-6 *Roseolovirus*, 387, 594b, 605
- HHV-7 *Roseolovirus*, 387, 594b, 605
- HHV-8 Kaposi's sarcoma. *See* Kaposi's sarcoma
- HHV-8 *Rhadinovirus*, 387
- HHV (human herpes virus), 387, 388f, 601–603. *See also* herpesviruses
- Hib. *See* *Haemophilus influenzae*, type B
- high cholesterol, antisense DNA and, 259t
- high-efficiency particulate air (HEPA) filters, 164, 188
- high-energy bond, 119, 120
- high-energy electron beams, 189
- high frequency of recombination (Hfr) cell, 234, 236f, 238f
- high G + C gram-positive bacteria, 280f, 302t, 318–320
- high pressure treatments, to control microbial growth, 189, 191t
- high-temperature short time (HTST) pasteurization, 187
- high-temperature short-time (HTST) pasteurization, 187
- high-throughput screening methods of soil samples, 560
- highly active antiretroviral therapy (HAART), 553
- HindIII* restriction enzyme, 248t, 249f
- hinge region of antibodies, 482, 482f
- hip replacement components, biofilms colonizing, 433
- histamine, 424, 464, 464f, 524
- in allergic reactions, 484, 529, 529f
  - complement system and, 468f, 469f
  - released by eosinophils, 456
- histidine (his)
- Ames test and, 230–231, 230f, 232b
  - replica plating technique and, 229–230, 229f
  - structural formula/characteristic R group, 42t
- histiocytes (fixed macrophages), 457, 460, 638, 639f
- histocompatibility antigens, 482, 538
- major histocompatibility complex (MHC) and, 482, 482f, 500f, 533–534
- tissue rejection and, 482
- histones, 76, 100t, 101, 276t
- Histoplasma*, interleukin-12 and, 499b
- Histoplasma* (*Ajellomyces*) *capsulatum*, 340t
- Histoplasma* (*Ajellomyces*) *dermatitidis*, 340t
- Histoplasma capsulatum*
- AIDS-associated, 550t
  - histoplasmosis caused by, 431t, 702–703, 702f, 706b
- histoplasmosis, 339, 431t, 702–703, 702f, 706b
- airborne transmission and, 412f, 413
  - amphotericin B effective against, 568
  - incubation period, 431t
  - portals of entry, 431t

- HIV, 5f, **20**, 545  
 as a provirus, 390, 546f, 547  
 as a retrovirus, 378t, **390**, 390f, 545  
 antigenic variation in, 547  
 clades (subtypes) of, 547  
 cytopathic effects of, 445t  
 DNA technology to track, 244f  
 early understanding of, 369, 545  
 emerging infectious diseases and, 419t  
 entry method of, 385, 386f, 545, 546f, 547  
 evading immune defenses, 443, 445t, 462, 547  
 fusion and, 385, 386f, 546f, 547  
 genetics and, 207  
 gp120 glycoprotein spikes and, **545**, 546f  
 HIV-1, HIV-2 subtypes and, 378t, 387, 390, 545, 547, 571  
 incubation period, 431t  
 infection. *See* HIV infection  
 macrophages and, 545, 547f  
 mechanisms for attacking immune system directly, 443  
 as mutation of simian immunodeficiency virus, 545  
 pathogenicity of, 545–547, 546f  
 portals of entry, 430, 431t  
 resistance to, 549  
 reverse transcriptase enzyme and, 387, 390, 545, 546f, 547  
 structure of, 545–547, 546f  
 survive in phagocytes, 462  
 transmission of, 245b, 251b, 254b, 257b, 258b, 551  
 vaccine development and, 258, 547  
 HIV infection, 545–550  
 active, 546f, 547, 547f  
 antiviral drugs to treat, 575–577  
 antivirals to treat, 575–577  
 APTIMA assay to detect, 545  
 blood banking and, 727b  
 CD4+ T cells and, 5f, 443, 545–550, 546f, 548f  
 cell counts during stages of, 547f, 548–549  
 chemotherapy and, 553, 575–577  
 Clinical Case, 245b, 251b, 254b, 257b, 258b  
 diagnostic methods, 550–551  
 distribution of cases, worldwide, 551, 552f  
 ELISA test to detect, 286, 287f, 521, 523f, 550  
 first known cases of, 369, 545  
 infants born to HIV-positive mothers and, 544  
 latent, 546f, 547, 547f  
 long-term nonprogressors and, 545  
 long-term survivors, 549–550  
 as notifiable infectious disease, 424t  
 persistent viral infection and, 396t  
 phases of, 547–549, 548f  
 progression of, 547–549, 548f  
 resistance to, 549  
 survival with, 544t, 549  
 transmission of, 245b, 251b, 254b, 257b, 258b, 551  
 treatment regimens, 553, 575–577  
 alpha interferon and, 473  
 cell entry inhibitors and, 553  
 chemotherapy, 553  
 colony-stimulating factor and, 259t  
 fusion inhibitors and, 553, **571**  
 integrase inhibitors and, 553, 571  
 interleukin-12 (IL-12) and, 499b  
 maturation inhibitors and, **553**  
 protease inhibitors and, 553, **575**  
 reverse transcriptase inhibitors and, 553, 575  
 vaccine development and, 258, 547–548  
 Western blotting to confirm, 286–287, 288f, 521, 550  
 hives, 528, 530–531  
 HLA (human leukocyte antigen) complex, 482, **538–539**, 538f, 538t  
 grafts and, 541  
 HLA typing, 538, 539t  
 HME (human monocytotropic ehrlichiosis). *See* ehrlichiosis  
 Hodgkin's disease  
 as acquired immunodeficiency, 544  
 Epstein-Barr virus and, 664  
 HLA typing to determine susceptibility, 539t  
 holdfasts of algae, **343–344**  
 holdfasts of lichen, **342**  
 Holmes, Oliver Wendell, 647  
 holoenzyme, **114**, 114f  
 home canning of foods, 185, 187  
 home pregnancy test, 520, 522f  
*Homo sapiens*, 278  
 homolactic (homofermentative) bacteria, **133**  
 hook of flagella, 81, 81f  
 Hooke, Robert, 6, 10f, 55  
 hookworms, 330, 360, 361, 364t, 738f, 740b, **741**, 741f  
 larvae bore through intact skin, 430  
 horizontal gene transfer, 213f, **232**, 275, **583b**  
 antibiotic resistance and, 575, **583b**  
*Wolbachia* and, 308b  
 hormones, proteins as, 41  
 hormones (genetically modified)  
 bovine growth hormone (bGH), 266, 267t  
 human growth hormone (hGH), 247, 259t  
 insulin, 2, 245, 247, 254, 257, 259t, 802  
 porcine growth hormone (pGH), 267t  
 somatostatin, 257  
 horsepox (extinct), 505  
 horses  
 anthrax and, 315  
 as disease reservoir, 413t  
 DNA vaccine against West Nile virus approved for, 508  
 eastern equine encephalitis in, 630, **634b**  
 influenza A virus subtypes and, 18, 374–375bb  
 reported cases of rabies in, 630f  
 western equine encephalitis in, 377t, 630, **634b**  
 hospital-acquired infections. *See* nosocomial infections  
 hospital nurseries, outbreaks of impetigo (pemphigus neonatorum) in, 588  
 hospitals  
 control of nosocomial infections in, 417  
 decontamination techniques, 199  
 intensive care units, epidemic nosocomial infections and, 416  
*Serratia marcescens* and, 311  
 Universal Precautions for health care workers (CDC), 546t  
 UV lamps to control microbes, 190  
 ventilation systems, nosocomial infections and, 416  
 water supply  
*K. pneumoniae* and, 76b, 86b, 88b, 95b, 97b  
*Legionella* and, 689  
 water supply lines in, *Legionella* and, 309  
 workers, resistance of to antibiotics, 576  
 host range (viral), **370–371**  
 ecological niches and, 374  
 species barrier crossings, 370–371, 374–375b  
 hosts  
 compromised, 415f, **416**, 417t  
 defenses  
 how pathogens penetrate, 431, 431t, 433–435, 435f, **447f**  
 how viruses evade, 443–444, 444f, 445t  
 IgA antibodies and, 435  
 innate immunity and, **451–475**, **476**. *See also* innate immunity  
 phagocytosis, bacterial capsules and, 433  
 virulence and, 432–433  
 definitive, **351**. *See also* definitive host  
 environments for parasitic helminths, 354, 355  
 how bacterial pathogens damage cells, 433–443  
 how pathogens enter, 430–433, 431t  
 how pathogens penetrate, 431, 431t, 433–435, 435f, **447f**  
 interactions, and viral phage therapy, 371, **579**  
 interactions of, emerging infectious diseases and, 418  
 intermediate, **351**. *See also* intermediate host  
 viral (mammalian cells in culture), 256–257  
 hot-air sterilization, **188**, 191t  
 hot environments, archaea found growing in, 274, 274f, 326, 326f  
 hot springs, microbes associated with, 156, 326  
 hot tubs/saunas, rashes and, 597  
 hot zone labs, 164–165, 165f  
 houseflies, as vectors, 365  
 household cleaning products  
 bacterial resistance and, 18–19  
 bleach, to disinfect norovirus, 201b  
 HPV (human papillomavirus), 387, 393  
 cervical cancers caused by, 387, 393  
 HPV-16, 393  
 vaccine, 259t, 393, 503t  
 HPV vaccine (Gardasil), 259t, 393, 506t, 543, 758  
 HSCs (hematopoietic stem cells), 540  
 HSV-1. *See* herpes simplex viruses  
 HSV-2. *See* genital herpes  
 HTLV-1 and HTLV-2 (human T-cell leukemia virus), 393, 396t  
 HTST (high-temperature short-time) pasteurization, **187**  
 HTST pasteurization, **187**  
 Huber, Robert, 10f  
 human activated protein C, 646  
 human cells, microRNAs and gene expression, 222–223, 223f  
 human diploid cell vaccine (HDCV) for rabies, 629  
 human diploid culture vaccine, 380  
 Human Genome Project, 260  
 human granulocytic anaplasmosis/HGA, 290, 424t, **654**, **656b**  
 human granulocytic ehrlichiosis, 290  
 human growth hormone (hGH)  
 industrial fermentation used to produce, 802  
 produced by genetically modified *E. coli*, 247, 259t  
 human herpesviruses (HHV), **387**, 594b, 596, 597–598, 598f. *See also* HHV-1 to HHV-8  
 latent infections and, 392, 394, 396t  
 human immunodeficiency virus. *See* HIV  
 human insulin. *See* insulin (human)  
 human leukocyte antigen (HLA) complex, 482, **538–539**, 538f, **539t**  
 bone marrow transplants and, 541  
 diseases related to, 539t  
 grafts and, 541  
 stem cells and, 540, 540f  
 tissue typing, 538–530, 538f  
 transplantation reactions and, 539–541  
 using PCR in matching donors, 539  
 Human Microbiome Project, **402**  
 human monocytotropic ehrlichiosis (HME). *See* ehrlichiosis  
 human papillomavirus (HPV), 377t, 387, 393  
 cervical cancers caused by, 387, 393  
 vaccine, 259t, 393, 503t, 506t, 543, 758  
 warts caused by, 377t, 387, 388f, 597b  
 genital warts, **758**, 758f, 761b  
 human parvovirus B19, 377t  
 Human Proteome Project, 260  
 human rabies immune globulin (RIG), 629  
 human reservoirs, **411**  
 human T-cell leukemia viruses (HTLV-1 and HTLV-2), 393, 396t  
 human-to-human transmission  
 of avian influenza viruses, 18  
 of Ebola hemorrhagic fever, 19



- humanized antibodies, **514**  
humidifiers, as disease reservoirs, 417  
humoral immunity, 479–480, 485–487, 500*f*. *See also* Antibodies  
antibody titer and, 497, 497*f*, **510**, 511*f*  
B cells and, 485–487, 486*f*, 487*f*  
immunological memory and, 497  
primary response, 497, 497*f*  
secondary response, 497, 497*f*  
spleen removal decreases, 494*b*, 543  
humors (body fluids), 480  
Huntington's disease, 225, 225*f*  
HUS. *See* hemolytic uremic syndrome  
HVP (hydrolyzed vegetable protein), *Salmonella tennessee* outbreak and, 294*b*  
hyaluronidase, **435**, 595  
therapeutic uses, 435  
hybridization reaction studies  
colony, **255**, 256*f*  
evolutionary relationships and, 277  
fluorescent in situ (FISH), 292, 293*f*  
forensic microbiology and, 261, 263*f*  
nucleic acid, 290, 291*f*, 292  
Southern blotting and, **261**, 262*f*, **290**, 291*f*, 292  
hybridomas, **512**, 513*f*  
hydatid cyst disease, **360**, 361*f*, 364*t*, **739**, 740*b*, 741, 741*f*  
hydatidosis. *See* hydatid cyst disease  
hydrocarbons  
bacteria that use as energy/carbon source, 235  
formed by diatoms, early planktonic algae, 348  
hydrochloric acid (HCL), 34*f*  
most microbes destroyed by, 430  
hydrogel, biofilm as, 160  
hydrogen bonds, **30–31**, 31*f*, **31*t***, 45*f*, 46*f*  
hydrogen (H)  
as a biofuel, microbes and, 815  
acids and, 34, 34*f*  
atomic number/atomic weight, 27*t*  
bases and, 34, 34*f*  
in biological oxidations, 120, 121*f*  
electronic configuration, 28*t*  
an energy source, 139, 141*f*, 143, 143*t*  
as fermentation end-product, 132*f*  
green bacteria and, 142, 143*t*  
in methane formation, 30, 30*f*  
molecule formation, 30, 30*f*  
in organic compounds, 36  
salts and, 34, 34*f*  
water molecules and, 33–34  
hydrogen ions, acid-base balance and, 34–35, 34*f*  
hydrogen peroxide  
as antiseptic, 199, 202*t*  
for aseptic packaging, 199, 202*t*  
catalase and, 104, 162, 199  
as disinfectant, 199, 202*t*  
magnetosomes can decompose, 95  
NADPH and, 463*b*, 466*b*, 472*b*  
peroxisome enzymes and, 104  
in plasma sterilization, 199, 202*t*  
toxicity and, 104, 160, 199, 462  
hydrogen sulfide  
anaerobic respiration and, 130  
biochemical tests to identify, 137, 137*f*  
Desulfovibrionales genera and, 312  
as energy source for bacteria, 14, 143, 306, 307  
green bacteria and, 142, 143*t*  
*Hydrogenomonas*, 143  
Hydrogenophilales, 300*t*  
hydrolase enzymes, 115*t*  
hydrolysis, **38**, 38*f*, 115*t*  
in DNA replication, 212*f*, 213  
hydrolytic reactions, 112  
hydrolyzed vegetable protein (HVP), *Salmonella tennessee* outbreak and, 294*b*  
hydrophilic molecules, 40, 40*f*  
phospholipids, 40, 40*f*, 89, 89*f*  
hydrophobia, rabies and, 629  
hydrophobic molecules, 40, 40*f*, 44, 45*f*, 89, 89*f*  
hydrothermal vents, deep-sea, 156, 157*b*, 326  
hydroxide ion, 34  
hydroxyl functional group, 36, 37, 41, 42*t*  
of alcohols, 36  
in fatty acids, 39, 39*f*  
hydroxyl radical, **160**, 462  
ionizing radiation and, 189  
hygiene hypothesis, 525  
hyperacute rejection, **541**  
hyperbaric chamber, to treat gas gangrene, **653**, 653*f*  
hypercholesterolemia, gene therapy, 16  
hypersensitivity (allergy), **528–531**, 528*t*  
anaphylactic (Type I), **528**. *See also* anaphylactic reactions  
cytotoxic (Type II), 528*t*, **532–534**, 532*t*, 533*f*, 534*f*  
delayed (Type IV), **535**, 536*f*  
desensitization to prevent, 531  
eosinophils increase during, 456  
IgE antibodies and, 481, 528–531, 528*t*, 529*f*  
immune complex (Type III), 528*t*, **534–535**, 534*f*  
to penicillin, 481, 530, 537*b*  
hyperthermophiles (extreme thermophiles), 4, **156**, 157*b*, 274, 274*f*, 280*f*, 302*t*, **326**, 326*f*  
hypertonic solution, 92*f*, **93**  
microbial growth and, 156, 157*f*  
hyphae, 4, 5*f*, 281, **332–333**, 332*f*, 333*f*, 340*t*  
of *Candida albicans*, 334*f*  
fragmentation and, 333  
lichen and, 342, 343*f*  
of *Mucor*, 5*f*  
of *Talaromyces*, 336*f*  
*Hyphomicrobium* genus/spp., 300*t*, **304**, 305*f*, 777  
hypochlorous acid, 192, 462  
hypotension, endotoxic shock and, 440  
hypothalamus, as body's thermostat, 466  
hypotonic environments, microbial growth and, 158  
hypotonic solution, 92*f*, **93**
- I**  
I gene, 221, 221*f*, 222*f*  
iamivudine, mode of action/uses, 564*t*  
ibritumomab (Zevalin), 509  
ibuprofen, 465  
ice cream  
algae-produced thickeners used in, 346  
pasteurization time/temperature and, 187  
ice formation, *Pseudomonas syringae* and genetically modified plants, 267*t*  
icosahedron-shaped viruses, 372*f*, 373  
ICTV (International Committee on Taxonomy of Viruses), 281, 374  
identification of microorganisms, by nutritional patterns, 140–143, 141*f*  
identification of microorganisms, 281–294  
biochemical tests, 284–287, 284*f*–287*f*  
cladograms and, 274*f*, 280*f*, 293–294, 294*f*  
dichotomous keys and, 285*f*, 293  
differential staining, 284  
DNA base composition, 289  
DNA fingerprinting, 289–290, 289*f*  
enzymatic activity tests, 284, 284*f*  
fatty acid profiles (FAME tests), 287  
flow cytometry, 287–289  
lab report form (example), 283, 283*f*  
metabolic characteristics, 284–287, 284*f*  
metabolic reaction tests, 281, 284, 284*f*  
microscopic examination, 281, 284  
morphological characteristics, 284  
nucleic acid amplification tests (NAATs), 290  
nucleic acid hybridization, 290, 291*f*, 292  
phage typing, 287, 289*f*  
polymerase chain reaction (PCR), 290  
of prokaryotes, 281, 284–294  
rapid identification methods, 285–286, 285*f*  
relationship of taxonomy to, 272  
serological tests, 286–287, 286*f*, 287*f*, 288*f*  
slide agglutination tests, 286, 286*f*  
by Western blotting, **286–287**, 288*f*  
idiophase, **803**  
iodoquinol (diiodohydroxyquin), 577  
IFNs (interferons), **471–473**. *See also* interferons  
IgA, 483, 483*f*, 483*t*, **484**, 489, 681  
IgA proteases, **435**, 479, **480–481**, 483*t*, 486  
serum IgA, 480  
IGAS (invasive group A *Streptococcus*), 19, 595–596  
IgD, 483, 483*f*, 483*t*, **484**  
activation of B cells to produce antibodies and, 484, 484*f*  
IgE, 483, 483*f*, 483*t*, **484–485**  
allergic reactions and, 484–485, 528–529, 528*t*, 529*f*
- IgG, **483**, 483*f*, 483*t*, 488, 493, 494*f*, 514–515  
desensitization process and, 531  
immune complex reactions and, 534, 534*f*  
maternal, passive immunity to fetus and, 483, 498  
IgM, 415*f*, **483**, 483*f*, 483*t*, 487*b*, 488, 493, 494*f*, 514–515, 516, 531  
IL-1. *See* interleukin-1  
IL-12. *See* interleukin-12  
illuminator, of compound light microscope, 55, 55*f*  
imidazoles, **574**, 574*f*  
imipenem, 88*b*, 95*b*, 564*t*, 569  
imipenem-resistant gram-negative infections, 95*b*  
imiquimod, **575**  
immersion oil, 57, 59*f*  
refractive index and, 57, 59*f*  
immortal cell lines, 380  
immune adherence. *See* opsonization  
immune complex autoimmune diseases, **537**  
complement deficiency and, 472*b*  
immune complex (Type II)  
hypersensitivity reactions, 528*t*, **534–535**, 534*f*  
immune deficiency diseases, **544*t***  
immune surveillance, **542**  
immune system  
adaptive immunity, 478–503  
aging and decline of, 465, 527  
biofilms and, 161  
complement system's role in, 466–470  
diagnostic immunology, 511–523  
disorders, 527–554  
AIDS, 545–554  
autoimmune diseases, 536–538  
cancer, 542–543  
Clinical Case, 528*b*, 531*b*, 541*b*, 544*b*, 554*b*  
HLA complex reactions, 538–542  
hypersensitivity, 528–531  
immunodeficiencies, 543–545  
extracellular killing by, 491  
innate immunity, 451–477  
opportunistic pathogenic fungi and, 340–341  
self vs. nonself recognition and, 477, 482, 485, 486, 492–493, 494, 500*f*, 532–536  
suppressed  
to prevent transplant rejection, 527  
susceptibility to nosocomial infections, 415, 416  
vaccinations, 498, 505–511  
immunity, **11**, **451**  
activation mechanisms, 452  
active, naturally or artificially acquired, 498, 498*f*  
adaptive, **452**, 452*f*, **478–503**. *See also* adaptive immunity  
cellular, **480**, 489–494, 500*f*. *See also* cellular immunity  
discovery of, 11  
first line of defense, 452*f*, 453–456, **474*t***  
chemical factors, 455, **474*t***

- normal microbiota, 455–456  
physical factors, 453–455, 453f, 454f, 474t  
skin and mucous membranes, 452f, 453–456, 474t  
herd, 409, 505, 598, 612  
humoral, 477, 482–486  
innate, 451–477, 452, 452f  
vs. adaptive, 452, 452f  
non-specific host defenses, 451–475  
overview, 452, 452f  
passive, naturally or artificially acquired, 494–495, 494f  
of population, disease spread and, 409  
second line of defense, 452f, 456–474  
antimicrobial substances, 466–474  
fever, 466  
inflammation, 463–466  
phagocytes, 460–463  
as something that can be acquired, 477  
third line of defense, 452f  
vaccination rates and, 409, 510b  
immunization, 498, 498f. *See also* vaccination  
immunoblotting (Western blotting), 286–287, 288f, 380, 521  
immunocompromised patients  
human parvovirus B19 and, 377t  
nosocomial infection susceptibility and, 415, 416  
immunodeficiencies, 543–545, 544f, 544t  
acquired, 544, 544t  
congenital, 543, 544t  
immunodiffusion tests, 515  
immunoelectrophoresis, 515  
immunofluorescence, 59, 61f. *See also* fluorescent-antibody (FA) technique  
immunogens, 481. *See also* antigens  
immunoglobulins (Ig), 481–485. *See also* antibodies  
classes of, 483–485, 483t  
complement fixation and, 483t  
functions of, 483t  
IgA, 483t, 484  
IgD, 483f, 483t, 484  
IgE, 483f, 483t, 484–485  
IgG, 483, 483f, 483t, 493, 494f, 509  
IgM, 483, 483f, 483t, 493, 494f, 509  
location in body, 483t  
molecular weight of, 483t  
placental transfer of, 494–495  
summary table, 483t  
immunological memory, 497, 497f  
immunologically privileged sites/  
tissues, transplant rejection and, 534–535  
immunology, 14, 16  
diagnostic, 511–523. *See also* diagnostic tools  
early history, 479, 505, 512  
future of, 521–522  
golden age of, 509  
practical applications  
diagnostic tools, 511–523  
vaccines, 498, 504, 505–511  
immunosuppression, in transplant surgery, 527, 541–542  
immunosuppressive drugs, 541–542  
opportunistic mycoses and, 340–341  
immunotherapy, 542–543  
for allergies, 526, 526f  
immunotoxin, 543  
impetigo, 317, 447, 593, 593f, 596b  
impetigo of newborn (pemphigus neonatorum), 593  
implants (medical)  
bacterial colonization on, 531b  
supercritical carbon dioxide to decontaminate, 199  
in-phase light rays, 57  
inactivated killed vaccines, 507–508  
inapparent infections (subclinical infections), 409, 494  
incidence of disease, 408  
incineration, sterilization and, 188  
inclusion bodies (viral), 443, 444f  
cytomegalic inclusion disease, 387, 658  
inclusion conjunctivitis, 609b, 610  
inclusions of prokaryotic cells, 79f, 94  
incubation period in infectious diseases, 410, 410f, 431t  
incubators, carbon dioxide, 164  
India ink, in capsule staining, 70, 70f  
indicator organisms in water purity tests, 786  
indicators, sterilization, 187, 187f  
indigo, produced by bacteria, 3b  
indinavir, 553, 576  
indirect contact transmission, 411, 412f  
in nosocomial infections, 414–417  
indirect ELISA tests, 519, 521, 523f  
indirect FA tests, 518–519, 520f  
indirect (negative) selection to identify mutant cells, 229–230, 230f  
indirect (passive) agglutination tests, 516–517, 516f  
indole, 3b  
induced pluripotent stem cells (iPS), 540  
inducer genes, 219, 221f, 222f  
quorum sensing, biofilms and, 56b, 161  
inducible enzymes, 219, 221f  
inducible operons, 221, 221f  
inducible promoters, 255  
induction, 219–221, 221f, 222f  
industrial applications of  
microbiology, 807–815  
alternative energy sources, 813–815  
amino acids products, 810–811  
antibiotics, 800  
microbes used to produce, 245, 247, 320, 341, 559–550, 560t, 563, 805  
biofuels, 807–808, 808f  
biotechnology, 808. *See also* biotechnology  
chemical detection microbes, 801b, 806  
citric acid products, 805  
commercial microbial products, 804–806  
copper production, 812, 813f  
enzyme products, 810, 811–812  
fermentation technology, 808–810  
food preservation, 800–807  
future of, 808  
microbes as industrial products, 812–813  
pharmaceuticals, 812, 812f  
renewable energy sources, 813–815  
vaccines, 812. *See also* vaccines  
vitamins, 812  
industrial fermentation, 808–810  
primary metabolite produced by, 809, 810f  
secondary metabolite produced by, 809, 810f  
industrially important bacteria  
lactobacilli, 316  
mining industry microbes, 245  
indwelling catheters  
biofilms and, 17, 18f, 161, 433, 586, 587f  
*Enterococcus faecalis*, *Enterococcus faecium* and, 317  
silver incorporated into, 195  
inert gases, 27  
infant botulism, 624  
infant diarrhea, pathogenic *E. coli* and, 235  
infants, ophthalmia neonatorum, silver nitrate and, 195  
infants born to HIV-positive mothers, 549  
infection, 402  
disease vs., 402  
focal, 409  
intoxication vs., 437  
local, 409  
systemic (generalized), 409  
infection control  
early methods of, 9, 11  
hand-washing as single most important activity, 417  
in hospitals, 417  
infections  
in digestive tract, vs. intoxication, 716  
drug-resistant, 12  
fungal, 339–341, 340t  
germ theory of disease and, 8, 11, 404–406, 477  
hospital-acquired. *See* nosocomial infections  
incubation periods and, 410, 410f, 431t, 442b  
local, 409  
nosocomial, 414–417. *See also* nosocomial infections  
primary, 409  
secondary, 409  
spread of, 411–414, 413t, 414t, 446  
disease reservoirs, 411  
transmission, 411–414, 413t, 414f, 414t  
subclinical (inapparent), 409, 494  
WBC types during initial/middle/late stages of, 457t  
infectious diseases, 17, 406. *See also* microbial diseases  
acute disease and, 406  
carriers of, 411  
chronic disease and, 409  
classification and, 408–409  
climate and, 410  
communicable disease and, 408  
contagious, 406  
control methods, 501. *See also* vaccines  
diagnosis of, 408  
DNA fingerprinting and, 261, 263, 263f, 289, 289f  
duration or severity of, 409  
emerging (EIDs), 17–21. *See also* emerging infectious diseases  
endemic disease and, 406  
epidemic disease and, 408–409, 408f  
etiology determination and, 406–408, 407f  
experimental inoculations, ethics of, 407–408  
frequency of occurrence and, 406  
genomics of pathogens and, 261  
incidence of, 406  
incubation periods, 410, 410f, 431t  
Koch's postulates and, 404–406, 405f  
noncommunicable diseases, 406  
norovirus outbreak (Clinical Focus), 261, 265b  
norovirus outbreak recurrence, 197b, 199b, 201b  
occurrence of, 406  
pandemic disease, 406  
patterns of, 409–410  
predisposing factors, 410  
prevalence and, 406  
reservoirs of infection, 411  
severity or duration of, 409  
signs, vs. symptoms in, 406  
sporadic diseases NS, 406  
spread of, 411–414  
disease reservoirs and, 411  
transmission, 411–414, 413t, 414t  
stages/sequence of events during, 410, 410f  
syndromes and, 406  
transmission  
by contact (direct or indirect), 411, 412f  
by droplets, 411, 412f  
by vehicle, 412–413, 412f  
vaccination rates, herd immunity and, 409, 505, 598, 612  
weather and, 410  
zoonoses, 411, 413t  
infectious mononucleosis, 377t, 387, 649b, 663, 664f  
caused by Epstein-Barr virus, 431t, 663  
as chronic disease, 409  
hemagglutination test to diagnose, 512  
incubation period, 431t  
portal of exit, 446  
portals of entry, 431t  
infectious proteins. *See* prions  
infertility, from pelvic inflammatory disease, 752, 761b  
inflammation, 452f, 463–466, 464f, 474t  
acute/chronic, 463  
chemokines important in, 492  
compliment activation and, 467, 468f, 469f, 488, 488f

- monoclonal antibodies to treat, 509  
phagocyte migration/phagocytosis  
  in, 464f, 465  
scar tissue and, 465  
as second line of defense, 452f, 463, 464f  
  signs/symptoms, 463  
  stages of, 463–465, 464f  
inflammatory acne, 455, **594**  
Inflammatory (moderate) acne,  
  **599–600**  
inflammatory response, 464f  
  of autoimmune diseases, 537  
  of tuberculosis, 463  
infiximab (Remicade), 512  
influenza (flu), **699–701**, 699f, 700t, 706b  
  1918–1919 pandemic, 700, 700t, 701  
  antigenic drift and, **700**, 700t  
  antigenic shift and, **374–375b**, 375f, **700**, 700t  
  antigenic variation and, 435  
  cytokine storm and, 497, 701  
  diagnosis of, 701  
  epidemiology of, 700  
  as pandemic disease, 406, 693  
  pediatric mortality, as notifiable  
    infectious disease, 424t  
  portal of exit, 446  
  portals of entry, 430, 431t  
  transmission methods, 411, 413t  
  treatment of, 701  
  vaccine, 14, 506f, 507t, 700–701  
  as zoonotic disease, 413t  
*influenza H1N1* virus (swine flu), **18**,  
  374–375b, 405f, 700–701, 700t  
influenza viruses, 378t, **378t**, **692–693**,  
  692f, 693t  
  antigenic drift and, **693–694**  
  antigenic shift and, **374–375b**,  
    375f, **693**  
  antigenic variation and, 509, 511  
  bird flu (avian influenza A H5N1),  
    **18**, 374–375b, 693  
    recent human cases, 374t  
  genome of, antigenic shifts and,  
    374–375b  
  glycoproteins, plasma membranes  
    and, 90  
  hemagglutination and, 371, 373f  
  incubation period, 431t  
  influenza A viruses, 374–375b, 378t  
    animal species found in, 18, 370b  
    avian influenza A H5N1 (bird  
      flu), **18**, 374–375b, 374t, 693  
    crossing species barrier, 374–375b  
    *Influenzavirus* A2, 373, 373f  
    pandemics, 374–375b, 374t  
    as potential biological weapon,  
      654b  
    subtypes of, 373f, 375b, 378t  
  portals of entry, 430, 431t  
  as potential biological weapon,  
    654b  
  subtypes of, 374–375b, 517  
  vaccines, 14, 506t, 507t, 509,  
    511, 694  
    avian influenza virus, 18, 374b  
    DNA vaccines and, 258  
    genetically modified, 259t  
*Influenzavirus*, 20, **692–693**, 692f, 693t  
  antigenic shifts and, 374–375b,  
    435  
  hemagglutinin (HA) spikes,  
    **692–693**, 692f  
  incubation period, 431t  
  neuraminidase (NA) spikes,  
    **692–693**, 692f  
  portals of entry, 431t  
  reservoirs/transmission method,  
    413t  
*Influenzavirus* A2, 373, 373f  
information storage, biological, 211.  
  See also genetics  
ingestion phase of phagocytosis,  
  461f, **462**  
INH (isoniazid), 18, 562t, **564t**, **569**,  
  684  
inhalation of fungal pathogens,  
  336, 339  
inhalation of pathogens, 7. See also  
  under airborne  
inhalational (pulmonary) anthrax, **652**,  
  654b, 655b  
  virulence of, 432  
  inheritance, epigenetic, 222  
inherited disorders  
  complement deficiencies, 470  
  familial insomnia (fatal), 395  
  Huntington's disease, 225  
  sickle cell disease, 225  
  xeroderma pigmentosum, 231  
inherited traits. See genetics  
inhibition by basic dyes, by gram-  
  negative vs. gram-positive  
  bacteria, 87t  
inhibition of enzymes, **118–119**,  
  118f, 119f  
injection site, microbial controls and,  
  182, 183t  
innate immunity, 451–475, **452**, 452f,  
  **478**. See also immunity  
  antimicrobial substances, 466–474,  
    474t  
  antimicrobial peptides, **473–474**,  
    **578**  
  complement system, 466–470  
  interferons, 471–473, 471f  
  iron-binding proteins, 473  
  blood's role in, 456–458, 457t,  
    637–638, 639f  
  chemical factors, 452f, 455  
  Clinical Case, 452b, 458b, 463b,  
    466b, 472b, 473b  
  fever, 466  
  first line of defense, 452f, 453–456,  
    **474t**  
  inflammation, 463–466, 464f  
  lymphatic system's role in, 458–459,  
    459f  
  lymph's role in, 637–638, 639f  
  mucous membranes and, 452f,  
    453–456  
  normal microbiota and, 452f,  
    455–456  
  overview, 452, 452f  
  phagocytes, 460–463, 461f, 637–638,  
    639f  
  physical factors, 451–452, 451f  
  second line of defense, 452f,  
    456–474, **474t**  
skin and, 452f, 453–456, 453f  
summary, by component/functions,  
  **474t**  
inner membrane. See plasma  
  (cytoplasmic) membrane  
inoculating loop sterilization, 188, 191t  
inoculation of embryonated eggs with  
  animal viruses, 379, 379f, 504  
inoculum, **162**  
inorganic compounds, **33–36**  
  acids/bases/salts, 34–35, 34f  
  water, 31f, 33–34, 34f. See also water  
insect bites  
  flea, 304, 311, 364t, 413t, 648  
  *Rickettsia* and, 304  
  sand fly, leishmaniasis and, 356t,  
    665  
insect venom  
  anaphylaxis and, 528, 528t, 529  
  desensitization success and, 531  
Insecta (class), 363, 364t  
insecticides  
  allergic reactions to *Bacillus*  
    *thuringiensis* (BT) toxin, 266  
  fire ants and, 348  
  protozoa *Nosema locustae* to kill  
    grasshoppers, 348  
insects  
  as arthropods, 331f  
  *Bacillus thuringiensis* toxin and,  
    315–316, 315f  
  blood-feeding, 350  
  chitin exoskeleton of, 99  
  diseases transmitted by, 362,  
    364t, 447  
  as eukarya, 6  
  evolutionary influence of *Wolbachia*  
    bacteria, 308b  
  in foodstuffs, radiation doses needed  
    to kill, 797t  
  plant resistance to, and genetic  
    engineering, 16  
  plant viruses that can multiply  
    inside, 395  
  symbiotic relationships, 106b  
  that are vectors, 364t  
  as vectors, 362, 364t  
  *Wolbachia* as symbionts of, 300t,  
    306, 308b  
insertion sequences (IS), **237**, 238f  
insomnia, fatal familial, 395  
instruments, surgical. See surgical  
  instruments  
insulin-dependent diabetes  
  mellitus, **538**  
insulin (human), 257  
  chemically synthesized genes  
    and, 254  
  *E. coli* bacteria used to produce, 245,  
    257, 259t  
  genetically modified, 257, 259t  
  industrial fermentation to  
    produce, 808  
  microbial enzymes used to produce, 2  
  produced by rDNA technology,  
    257  
integral proteins, 89f, 90. See also  
  transporter proteins  
  of plasma membrane, 89f, 90, 91  
  role in facilitated diffusion, 91–92, 91f  
  as transmembrane proteins, 90  
  as transporter proteins (permeases),  
    91, 91f, 92  
integrase inhibitors, **571**  
  to treat HIV infection, 548, 576  
interference (relative darkness), in phase-  
  contrast microscopy, 57, 60f  
interferons (IFNs), 14, **444**, **471–473**,  
  471f, **474t**, **496**, **570**  
  alpha. See alpha interferon  
  as antiviral drugs, 471–473, 471f,  
    564t, 575  
  beta. See beta interferon  
  chemically synthesized genes and  
    production of, 254  
  as cytokines, 471, 496  
  discovery of, 14, 16  
  gamma. See gamma interferon  
  human types of, 471  
  as potential anticancer agents, 472  
  as rDNA products, 259t, 472  
  in second line of host defenses, 474t  
  side effects of, 471  
  toxicity and, 471  
  viral sensitivity to, 370t  
interleukin-1 (IL-1), **440**  
  fever and, 466  
interleukin-12 (IL-12), **499b**  
  HIV and, 499b  
  humoral response and, 499b  
  measles virus and, 499b  
  as promising “magic bullet”  
    therapy, 499b  
  psoriasis treatment success and,  
    499b  
interleukins, **496**, 499b  
  genetically modified, 259t  
intermediate bodies, *Chlamydomonas*  
  *psittaci* and, 323f  
intermediate filaments, 101  
intermediate host, 351, 364t  
  of *Echinococcus granulosus*, 360,  
    361f, 364t  
  of *Paragonimus kellicotti*,  
    357–358, 359f  
  of *Plasmodium vivax*, 351, 352f  
  of selected parasitic helminths,  
    364t  
*International Code of Botanical*  
  *Nomenclature*, 278  
*International Code of Zoological*  
  *Nomenclature*, 278  
International Committee on  
  Systematics of Prokaryotes, 279  
International Committee on  
  Taxonomy of Viruses (ICTV),  
  282, 375  
*International Journal of Systematic and*  
  *Evolutionary Microbiology*, 278  
interstitial fluid, 458, 459f, 644, 645f  
interstitial spaces, 644  
intestinal bacteria  
  antibiotic-resistant genes in, 405  
  ecological balance and, 310  
  normal, 301t, **310–312**, **404t**  
intestinal parasites, 330, **364t**  
  flatworms, 356–358, 358f–361f, 364t  
  protozoa, 356t  
  roundworms, 360–362, 361f,  
    362f, 364t  
  tapeworms, 358–360, 358f–361f,  
    364t



- intestines, normal microbiota of, 301*t*, 310–312, 326, 404*t*
- intoxication, 437
- botulism as special case of, 717
- in digestive tract, **716–717**
- domoic acid, **346**
- infection vs., 331*f*, 437, 716–717
- staphylococcal, 717–718, 717*f*
- intracellular antigens
- cellular immunity and, 486, 500*f*
- humoral immunity and, 486
- intracellular growth, as pathogenic mechanism, 435, 447*f*
- intracellular parasites, 300*t*, 302*t*, 303
- viruses as, 281, **370**, 370*t*
- intracellular pathogens, obligate, 300*t*, 301*t*
- intravenous (IV) catheters
- nosocomial bacteremia and, 416, 417*t*, 423*b*
- P. fluorescens* (Clinical Case), 154*b*, 166*b*, 175*b*, 177*b*
- introns, 211*t*, **218**, 219*f*, **253**, 254*f*, 260
- viroids and, 397
- intubation devices, as disease reservoirs, 416
- invasins, **435**, 447*f*
- invasive group A *Streptococcus* (IGAS/"flesh-eating bacteria"), 19
- iodine (I)
- atomic number/atomic weight, 27*t*
- as disinfectant, **193–194**, 201*t*, 202*t*
- glycogen/starch granules and, 95
- in Gram stain mechanism, 86
- as mordant, 68*f*, 86
- in water treatment, 194, 202*t*
- iodophors, **193–194**, 202*t*
- ionic bonds, **29–30**, 29*f*, **31*t***
- ionization (dissociation), **34**, 34*f*
- ionizing radiation, **189–190**, 190*f*, 191*t*
- as mutagenic, 227
- ions, **29**, 29*f*
- Iospora belli* (protozoa), AIDS-associated, 550*t*
- iPS (induced pluripotent stem cells), 535
- Ireland's potato blight, caused by *Phytophthora infestans*, 344
- Irish moss, 343
- iron-binding proteins, **473**
- siderophores and, **436**, 436*f*, **473**
- iron (Fe)
- atomic number/atomic weight, 27*t*
- biofilms and, 161
- as cofactor, 115
- cyanide and, 118
- enzyme inhibition and, 118
- human requirements for, 473
- lactoferrin and, 161, 436
- oxide, in magnetosomes, 95
- as requirement for bacterial growth, 436, 473, 639
- siderophores and, 436, 436*f*, **473**
- irradiation of foodstuffs, **796–797**
- doses needed to kill various organisms, 796*t*
- electron-beam accelerators used in, 797, 798*f*
- gamma ray processing, 797, 798*f*
- irradiation logo, 797*f*
- IS (insertion sequences), **237**, 238*f*
- ischemia, **646**
- isocitrate lyase, 115*t*
- isocitric acid, 125, 126*f*, 147*f*
- isografts, **540**
- isoleucine (Ile)
- E. coli* and synthesis of, 119, 119*f*
- structural formula/characteristic R group, 42*t*
- isomerase enzymes, 115*t*
- isomers, **38**
- of amino acids, 41, 43*f*
- isoniazid (INH), 18, 562*t*, **564*t***, **569**, 572, 684
- isoprenoids, as genetically modified product, 257
- isopropanol (rubbing alcohol), 37
- as disinfectant, 195, 202*t*
- isopropyl alcohol, 132*f*
- Isospora belli*, AIDS-associated, 550*t*
- isotonic solutions, 92*f*, **93**, 156, 157*f*
- isotopes, **26–27**
- isotretinoin (Accutane), 455, 600
- Isthmia nervosa* (diatom), 343*f*
- itraconazole, 574, 606
- IV catheters. *See* Intravenous (IV) catheters
- ivermectin, 566*t*, 577
- produced by *Streptomyces avermectinus*, 577
- to treat lice, 603
- veterinary applications, 577
- Iwanowski, Dimitri, 14, 369
- Ixodes*
- as vector for babesiosis, 352, 364*t*
- as vector for ehrlichiosis, 364*t*, 413*t*
- as vector of Lyme disease, 364*t*, 413*t*, 658
- life cycle of, 657*f*
- Ixodes pacificus* (tick), Lyme disease vector on Pacific coast, 364*f*, 413*t*, 658, 659*f*
- Ixodes scapularis*
- as vector for *Babesia microti*, 352, 364*t*
- as vector for Lyme disease, 658, 659*f*
- Ixodes* spp., 364*t*
- J**
- j (joining) chain, 483, 483*t*
- Jacob, François, 10*f*, 15, 219
- Janssen, Zaccharias, 55
- Japanese encephalitis, **631–632**
- jeans (designer "stone-washed"), microbes and, 3*b*
- Jenner, Edward, 10*f*
- smallpox vaccine and, 11, 505
- Jerne, Niels Kai, 13*t*, 512
- "Jesuit's powder", 577
- jock itch (tinea cruris), **605**
- joints, artificial, biofilms and, 17, 18*f*
- K**
- kanamycin resistance, 238*f*
- Kaposi's sarcoma, 20, 377*t*, 387, 550*t*
- in AIDS patients, 549, 550*t*
- alpha interferon to treat, 472–473
- early recognition of HIV connection, 20, 545
- Karenia brevis*, 346
- karyogamy, **335**, 336*f*, 338*f*
- Kauffmann-White scheme, 310–311
- Kefir (fermented milk beverage), 806
- kelp (brown algae), **345–346**, **345*t***
- keratin, **340**, 340*t*, **453**, 453*f*, **590**
- dermatophytes degrade, 340, 340*t*
- fungi and, 340, 340*t*, 430
- as resistant barrier of skin, 404*t*, 453, 453*f*, 584, **590**
- keratinase, 340
- keratitis, 356*t*, 605
- Acanthamoeba*, **605**
- herpetic, **605**
- keratoconjunctivitis, 337, 340*t*, 356*t*
- Ketek (telithromycin), 565*t*, **571**
- ketoconazole, 566*t*, 574, 591
- ketolides, **571**
- ketone functional group, 36*t*
- kidney dialysis
- antibiotic resistance developing from, 423*b*
- disinfectants used in, 194
- patients at risk for gram-positive sepsis, 640
- kidney diseases
- hemolytic uremic syndrome, 424*t*, 718
- leptospirosis, **746–747**, 747*f*, **748*b***
- pyelonephritis, **746**, 748*b*
- kidney transplant patients, impaired innate body defenses and, 465
- kidneys, 750, 750*f*
- glomeruli, 529
- kilometer (km), **54*t***
- kinases, **434**
- kinetic energy, heat absorption by molecules and, 34
- Kingdom Monera (Prokaryotae), 273
- Kingdom Protista, Haeckel's proposal, 273
- kingdom (taxonomic), defined, **278**, 279*f*
- kinins, **464**, 464*f*
- Kirby-Bauer test (disk-diffusion method), **578**, 578*f*
- kissing bug (*Triatoma*), 350, 356*t*, 363*f*, 364*t*, 413*t*, 661
- Kitasato, Shibasaburo, 10*f*
- Klebsiella* genus/spp., 301*t*, **311**
- capsule of and virulence, 80, 433
- as normal microbiota of large intestine, 404*t*
- as normal microbiota of urethra, 404*t*
- resistance plasmid R100 and, 236–237
- Klebsiella pneumoniae*, 282*b*, 311
- capsule staining to identify, 70*f*
- carbapenem-resistant, 207
- Clinical Case, 76*b*, 86*b*, 88*b*, 95*b*, 97*b*
- endotoxin lipid A and, 88*b*
- nosocomial infections and, 76*b*, 86*b*, 88*b*, 95*b*, 97*b*, 416*t*
- as superbug, 580
- virulence and, 80, 433
- Klug, Aaron, 10
- km (kilometer), metric/U.S. equivalent, 54*t*
- Koch, Robert, 8, 10*f*, 11, 406–408, 407*f*, 512, 650
- Koch's postulates, **11**, **406–408**, 407*f*
- Köhler, Georges J. F., 13*t*, 512
- Komagataelia pastoris* (yeast), genetically modified superoxide dismutase produced by, 259*t*
- Koplik's spots, 604
- Korean hemorrhagic fever, 378*t*
- Krebs cycle, 122, 123*f*, **125–130**, 126*f*
- amino acid biosynthesis and, 145
- anaerobic conditions and, 130
- ATP yields and, 130*t*
- in carbohydrate catabolism, 122
- catabolism of various food molecules and, 136*f*
- in cellular respiration, 123*f*, 125–130
- in integration of metabolic pathways, 146, 147*f*
- lipid biosynthesis and, 144, 145*f*
- in lipid catabolism, 135, 135*f*
- nucleotide biosynthesis and, 145–146, 146*f*
- in protein catabolism, 135
- Krebs, Edwin G., 13*t*
- Krebs, Hans A., 13*t*
- kumis (fermented milk beverage), 806
- Kupffer's cells, 460
- kuru, 395, **637**, **638*b***
- L**
- L-amino acids, 41, 43*f*
- L forms of bacteria, **88**
- L-isomers, 41
- LAB (lactic acid bacteria), 301*t*, 456
- lab report form (example), 283, 283*f*
- laboratory tests. *See* biochemical tests
- lac operon, 220–222, 222*f*, 257, 384
- lac repressor, 221, 223*f*, 384
- lac structural genes, 220
- lacrimal apparatus, **454**, 454*f*
- tears and innate immunity defenses, 451, 474*t*
- lacrimal canals, 454, 454*f*
- lacrimal glands, 454, 454*f*
- lactate dehydrogenase, 115*t*
- lactic acid
- aerotolerant anaerobes and, 160
- in amphibolic pathways, 147*f*
- bacteria used in winemaking, 806, 807*f*
- fermentation and, **132–133**, 132*f*, 133*f*
- industrial/commercial uses for, 134*t*
- Streptococcus* and, 134*t*
- lactic acid bacteria (LAB), 133, 301*t*, 316, 456
- lactic acid fermentation, **132–133**, 132*f*, 133*f*, 134*t*
- Lactobacillales, 301*t*, **316–317**, 316*f*
- lactobacilli
- as normal microbiota of newborn's intestine, 402
- as normal microbiota of vagina, 404*t*, 455, 751, 763
- used in acidic-fermented foods, 160
- Lactobacillus acidophilus*, 455
- Lactobacillus delbrueckii*, 134*t*
- Lactobacillus delbrueckii bulgaricus*, used to make yogurt, 799
- Lactobacillus* genus/spp., 301*t*, 314, **316**
- as a fastidious microbe, 162
- fermentation and, 132*f*, 133, 134*t*
- industrial importance of, 134*t*, 316

- as normal microbiota of large intestine, 404t  
as normal microbiota of mouth, 404t  
as normal microbiota of urethra, 404t  
as normal microbiota of vagina, 404t  
*Lactobacillus plantarum*, sauerkraut and, 134t  
lactoferrin, 161, 436, 473  
lactose (milk sugar), 38  
fermentation by enteric bacteria and, 284f  
intolerance and, 530  
*lac* operon and, 22f, 220–222, 257, 384  
*lac* repressor, 384  
*lac* structural genes, 220  
*lacZ* gene, 221f, 251f  
metabolism in *E. coli*, 219, 221f, 222f, 223f  
lactose operon regulation, 219–222, 221f, 222f, 223f  
*lacZ* gene, 221f, 223f, 249, 249f, 255, 255f  
lag phase, in bacterial growth, 170, 170f  
lagging strand in DNA replication, 212f  
lake bacteria, 304, 776. *See also* freshwater microbiota  
LAL (limulus amoebocyte lysate) assay, 441, 442b, 444b  
*Laminaria japonica*, 346  
lamivudine, 566t, 575  
Lancefield, Rebecca C., 10f, 14, 286  
landfills  
bacterial biosensors to detect pathogens/pollutants, 786b  
degradation of synthetic chemicals in, 780–781  
Landsteiner, Karl, 532  
Langerhans cells/Langerhans DC, 494  
laparoscopic surgical instruments, sterilizing, 198–199, 201  
large intestine, 459f  
microbial antagonism in, 403–404  
normal microbiota of, 404t  
parasitic helminths and, 364t  
Lariam (mefloquine), 562t, 577, 664  
larva migrans infection, 360  
laryngitis, 682  
Lassa fever, 378t, 666, 667b  
as potential biological weapon, 654b  
latency, 385t  
viral, 383, 384, 394, 394f, 396t  
latent disease, 409  
latent infections (viral), 394, 394f, 396t  
examples, 396t  
HIV infection, 396t, 547, 547f, 548f, 553  
provirus and, 391, 547, 547f, 548f  
latent virions in HIV, 547, 547f  
latex agglutination tests, 511–512, 511f, 677  
latex allergy, 535, 536f  
lattices, 514  
Lavoisier, Anton Laurent, 7  
LD<sub>50</sub>, to express potency of toxins, 432  
LDL-receptor deficiency, 16  
lead, used in staining of specimens, 62  
leading strand in DNA replication, 212f  
leafhoppers  
potato yellow dwarf virus transmitted by, 396t  
wound tumor virus transmitted by, 396t  
lectin pathway of complement activation, 467, 470f  
lectins, 467, 469, 470f  
binding of, 351  
mannose-binding lectin (MBL), 469, 470f  
Lederberg, Joshua, 10f, 13t, 15  
*Legionella* genus/spp., 301t, 309  
colonize hospital warm-water lines/air conditioning systems, 309  
*Legionella pneumophila*  
Legionnaires' disease caused by, 309, 406, 419t, 689  
phosphoprotein synthesis by bacteria and, 44  
Legionellales, 301t, 309  
legionellosis (Legionnaires' disease), 309, 406, 419t, 694, 695b  
erythromycin effective against, 566  
as notifiable infectious disease, 424t  
outbreak (case study), 698b  
*Leishmania braziliensis*, 665, 666  
*Leishmania donovani*, visceral leishmaniasis caused by, 656b, 665  
*Leishmania* (protozoa), 356t, 665  
can survive in phagocytes, 462  
interleukin-12 and, 499b  
leishmaniasis, 356t, 462, 656b, 672–673, 672f  
American, 673  
cutaneous, 665b, 672, 672f  
mucocutaneous, 656b, 672–673  
visceral (*kala azar*), 656b, 672  
length, metric measurement units of, 54, 54t  
lenses of microscopes  
early, 7, 7f, 54–55  
electromagnetic, 61–64, 63f  
in electron microscope, 61, 63f  
light, 55–57, 55f, 59f, 60f  
*Lentivirus* HIV, 378t  
budding of, 392, 392f  
as retrovirus, 378t, 390  
lepromatous (progressive) form of leprosy, 619, 620f  
leprosy (Hansen's disease), 318, 319, 406, 625–626, 625f, 632b  
antibiotics to treat, 572, 626, 632b  
culturing leprosy bacillus, 544f, 626  
diagnosis of, 70, 626  
*Mycobacterium leprae* causing, 319, 625  
as notifiable infectious disease, 424t  
types of, 625, 625f  
vaccines useful for, 626  
*Leptospira* genus/spp., 83f, 302t, 325  
as human pathogen, 302t, 325, 748f  
reservoirs/transmission method, 413t  
*Leptospira interrogans*, 748b, 749, 749f, 752, 753f  
leptospirosis, 325, 413t, 749, 749f, 752–754, 753b, 753f  
Clinical Case, 750b, 754b, 756b, 763b  
disease reservoirs for, 413t  
pulmonary hemorrhagic syndrome form of, 753–754  
transmission due to, 413t  
waterborne transmission and, 411, 413t  
lesions, skin, 591, 592f  
lethal dose, 432, 442t  
lettuce, norovirus infection outbreak, 265b  
leucine (Leu), structural formula/characteristic R group, 42t  
*Leuconostoc mesenteroides*  
culture media recipe, 162, 163t  
pentose phosphate pathway and, 125  
leukemia, 378t, 393  
bone marrow transplants and, 541  
chicken, 392  
feline, 393  
genetically modified CSF therapy for, 259t  
human T-cell viruses (HTLV-1, HTLV-2) and, 393, 396t  
as latent viral infection, 396t  
patients, mucormycosis and, 341  
leukocidin toxin, 423b  
produced by *S. aureus*, 76f, 423b, 581  
leukocidins, 439, 462  
leukocyte esterase, 746  
leukocytes (white blood cells), 456, 457t, 463b  
agranulocytes, 456, 457t  
basophils, 456, 457t  
decreases/increases in, 458  
differential white blood cell count, 457t, 458  
eosinophils, 456, 457t  
granulocytes, 456, 457t  
polymorphs, 456  
leukocytosis, 463b  
leukoplakia, oral, in HIV infection, 549, 550t  
leukotoxins, 438  
leukotrienes, 464, 464f, 529  
Level 4 labs, 164–165, 165f  
LGV (lymphogranuloma venereum), 322, 462, 762, 767b  
libraries  
cDNA, 253  
genomic, 252–253, 253f  
phage library, 253f  
plasmid, 253f  
lice (pediculosis), 363, 363f, 364t, 365, 597b, 608–609, 608f  
head, ivermectin effective against, 572, 608  
Lyme disease and, 325  
*Pediculus* and, 363f, 364t, 602  
sucking, 364t  
treatments for, 608–609  
typhus (epidemic) and, 304  
LiceMD (lice therapy), 608  
lichens, 342, 343f, 779  
air quality testers and, 342  
as major food for tundra herbivores, 342  
lidocaine, 201b  
*Leishmania* genus/spp., 330  
life, definition of, 370  
life-support processes. *See* metabolism  
ligands (adhesins), 432–433, 432f  
in receptor-mediated endocytosis, 100–101  
ligase (DNA), 111t, 215t  
light chains of antibodies, 482, 482f, 483t  
light-dependent (light) chemical reactions, 138, 139f  
light-independent (dark) chemical reactions, 138, 139f  
light microscopy (LM), 55–60, 55f, 58f, 59f, 60f, 65t  
brightfield, 57, 60f, 65t  
compound light, 55–57, 55f  
confocal, 59–60, 62f, 66t  
darkfield, 57, 60f, 65t  
differential interference contrast, 59, 61f, 65t  
fluorescence, 59, 61f, 65t  
magnification/specimen sizes and, 58f  
phase-contrast, 57, 60f, 65t  
preparing specimens for, 64, 67–71  
resolution and, 56–57  
summary of (features/typical image/uses), 65t–67t  
tick image, 58f  
light-repair enzyme (photolyase), 211t, 227–228, 228f  
light (visible)  
as energy source, 121, 138, 139f, 141f. *See also* photosynthesis  
in microscopy, 55–60  
ultraviolet. *See* ultraviolet light  
lime  
chloride of, 181, 194  
copper sulfate mixed with as fungicide, 196  
limnetic zone, 782–783  
limulus amoebocyte lysate (LAL) assay, 441, 442b, 444b  
*Limulus polyphemus* (crab), endotoxin testing and, 441  
lindane, 602, 603  
linezolid (Zyvox), 565t, 572  
Linnaeus, Carolus, 3, 10f, 273, 279  
lipases, in lipid catabolism, 134, 135f  
lipid A, 85f, 86, 440, 470  
antimicrobial proteins (AMPs) and, 473  
lipid bilayer, 89, 89f  
osmosis through, 91f, 92–93, 92f  
simple diffusion through, 91, 91f  
lipid-carbohydrate complex, alternative pathway of complement activation and, 466–467, 466f  
lipid catabolism, 133–135, 135f, 136f  
lipid inclusions, 95  
lipids, 38–40, 39f, 40f  
catabolism of, 133–135, 135f, 136f  
coenzymes and, 115t  
complex, 40, 40f  
fats (triglycerides), 39–40, 39f  
in gram-negative vs. gram-positive bacteria, 87t

- in lipoproteins, 44  
phospholipids, 40, 40f  
simple, 39–40, 39f  
synthesis of, 144, 145f
- lipopeptides, 565t, 572
- lipophilic viruses, biocidal resistance and, 200
- lipopolysaccharide (LPS), 85f, 86  
complement system evasion and, 470  
endotoxins and, 440  
in gram-negative vs. gram-positive bacteria, 87t  
Gram staining and, 69  
immunity and, 452  
selective toxicity of antibiotics and, 555
- lipoproteins, 44  
as adhesins (ligands), 432–433  
in gram-negative vs. gram-positive bacteria, 87t, 440
- lipoteichoic acid, 84, 85f
- Lister, Joseph, 9, 10f, 11, 181, 194, 415
- Lister, Joseph Jackson, compound microscope and, 55
- Listeria* genus/spp., 301t, 317  
actin of host used to self-propel, 435  
in milk, flow cytometry to detect, 288–289
- Listeria monocytogenes*, 317, 619–621, 620f, 623b  
adhesin production in, 433  
can grow at refrigerator temperatures, 317, 620  
can survive in phagocytes, 462, 620  
membrane attack complexes produced by, 462  
meningitis caused by, 619–621, 620f, 623b  
pregnancy dangers and, 317, 619  
sepsis caused by, 620
- listeriosis, 189, 462, 619–621, 620f, 623b  
cell-to-cell spread of, 619, 620f  
as foodborne infection, 619, 623b  
as notifiable infectious disease, 424t
- lithotrophs (autotrophs), 140–141, 141f
- litmus paper, extracted from lichens, 342
- littoral zone, 782  
algal habitats, 344f
- live attenuated vaccines, 507
- liver, parasitic helminths and, 364t
- liver cancer  
hepatitis B virus and, 393, 396t  
vaccine and, 543
- liver flukes, 356, 357, 358f, 364t
- liver transplantation, HLA typing and, 541
- liver tumors, caused by hepatitis B virus, 377t
- livestock  
animal feed antibiotics, 554, 562t, 565, 575, 583b  
antihelminthic (ivermectin) to treat, 571  
bovine growth hormone and, 266, 267t  
as disease reservoirs, 413t
- Pasteurella*-caused sepsis in cattle, 312
- lizards, 311
- LM. See light microscopy
- lobar pneumonia, 693
- local infection, 409
- localized anaphylaxis, 528, 530–531, 530f
- lockjaw, 439, 662. See also tetanus toxin
- log phase (exponential growth phase), in bacterial growth, 170, 170f
- logarithmic representations of bacterial populations, 169–171  
growth phase, 170–171, 170f
- lophotrichous flagella, 80f, 81
- low-density lipoprotein (LDL) deficiency, 16
- low G + C gram-positive bacteria, 280f, 301f, 314–320
- LPS. See lipopolysaccharide
- LSD (lysergic acid diethylamide), 445
- luciferase enzyme, bioluminescence and, 56b, 778
- lumbar puncture (spinal tap), 619, 620f
- lung flukes, 356–358, 358f, 359f, 364t
- Luria, Salvador E., 10f
- lux operon, bacterial biosensors and, 786b
- lyase enzymes, 115t
- Lyme borreliosis. See Lyme disease
- Lyme disease, 364t, 411, 413t, 656b, 658–660, 659f, 660f. See also *Borrelia burgdorferi*  
*Borrelia* and, 325, 658  
causative agent/arthropod vector, 414t  
diagnosis of, 660  
disease reservoirs for, 413t, 658–658, 659f  
as emerging infectious disease, 419t  
increases in, and animal control measures, 418  
as notifiable infectious disease, 424t  
reported cases 1992–2007, by year, 424f  
reported cases 2007, by month, 424t  
reported cases by county, 2008, 658f  
symptoms, 656b, 658–659, 660f  
tick (*Ixodes*) as vector, 363, 363f, 364t, 365, 414t, 652–653, 653f  
transmission due to, 413t  
Western blotting to diagnose, 287, 288f
- lymph, 458, 459f, 644, 645f
- lymph capillaries, 644, 645f
- lymph nodes, 458, 459f, 490b, 644–645, 645f  
site of activation of T cells, B cells, 458, 459f, 638  
swollen (buboes), 638, 648f
- lymphangitis, 646, 646f
- lymphatic capillaries, 458, 459f, 644–645, 645f  
relation to tissue cells, blood capillaries, 459f
- lymphatic ducts, 458, 459f
- lymphatic system, 458–459, 459f, 643–645, 645f
- cardiovascular system's relationship with, 643–645, 645f
- microbial diseases of, 637–673  
bacterial, 638–655, 649b, 650b, 656b  
helminthic, 666–667, 668b  
protozoan, 650b, 656b, 660–666  
vector-borne, 648, 652–655, 656b  
viral, 649b, 655–660  
structure/function, 459f, 644–645, 645f
- lymphatic vessels/lymphatics, 458, 459f, 644, 645f
- Lymphocryptovirus* (HHV-4/Epstein-Barr virus), 377t, 387
- Burkitt's lymphoma associated with, 393, 649b, 662–663, 663f  
cancer and, 393  
incubation period, 431t  
infectious mononucleosis caused by, 431t, 649b  
portals of entry, 431t  
pregnancy and, 760  
reactivated in HIV/AIDS patients, 549  
typical U.S. prevalence of antibodies against, 567, 567f
- lymphocytes, 457t, 458  
B. See B cells  
functions of, 480  
gamma interferon produced by, 471  
natural killer (NK) cells and, 457t, 458, 474t, 495, 496t  
T. See T cells  
as third line of defense, 452f
- lymphocytic choriomeningitis, 378t
- lymphogranuloma venereum (LGV), 322, 462, 762, 767b
- lymphoid tissue, 458–459, 459f, 490b
- lymphocytes of, 458
- lymphoma  
Burkitt's, 377t, 393, 649b, 655–656, 657f  
human, 393
- lyophilization (freeze-drying), 168, 191t  
desiccation and, 189
- lysergic acid diethylamide (LSD), 445
- lysine (lys)  
allergic contact dermatitis and, 530  
structural formula/characteristic R group, 42t
- lysis, 84, 93, 381, 382f, 383  
osmotic, 88, 93
- lysogenic conversion, 442, 447f
- lysogenic cycle of viral multiplication, 381, 383–385, 383f, 385t
- lysogenic phages (temperate phages), 383–384, 383f  
toxin production and, 384  
of *Vibrio cholerae*, 442
- lysogeny, 383–385, 383f  
pathogenicity and, 441–442  
phage conversion and, 384, 442  
prophages, 383f, 384, 442  
specialized transduction and, 384, 384f
- Lysol, 192, 193f
- lysosomes, 98f, 103  
in phagocytosis, 461f, 462
- toxic oxygen products produced by, 462
- lysozyme, 87t, 88, 455, 713  
cell wall damage done by, 88, 88t, 93, 455  
gram-positive bacteria and, 88, 88t  
immunity functions of, 455, 474t  
in perspiration, 590  
in perspiration, 455  
phage, 381, 383  
in phagocytosis, 462  
in tears, 88, 455
- Lyssavirus*, 378t, 630. See also rabies; rabies virus
- lytic cycle, 381–383, 382f
- M**
- M cells (microfold cells), 489, 490f, 716  
enteroinvasive *E. coli* and, 723  
Shiga toxin and, 718, 718f
- m (meter), metric/U.S. equivalent, 54t
- M protein, 433  
microbial evasion of phagocytosis and, 462  
rheumatic fever and, 648  
*Streptococcus pyogenes* and, 317, 432, 462, 595, 595f
- Mab-CD3 (muromonab-CD3), 259t, 544b, 554b
- mabs. See monoclonal antibodies
- MAC (membrane attack complex), 438f, 462, 467, 468f
- MAC-resistant bacteria, 467
- MacConkey's agar, 746, 748f
- MacGregor tomatoes, 266, 267t
- MacKinnon, Roderick, 13t
- MacLeod, Colin M., 10f, 15, 47, 232
- Macrocystis porifera* (brown algae), 344f
- macrolides, 565t, 571, 571f
- macromolecules, 33, 37  
polysaccharides as, 38
- macronucleus, of *Paramecium*, 349f, 353f
- macrophages, 456, 457t, 458, 460f, 494–495, 495f  
activated, 495, 495f  
in adaptive cellular immunity, 463, 487, 494–495, 495f  
as antigen-presenting cells, 494, 494f  
cathelicidins produced by, 473  
defensins produced by, 473  
fixed, 460, 638, 639f  
free (wandering), 460  
gamma interferon and, 471  
HIV in, 545, 547f  
HIV infection and, 545, 546f, 547  
in inflammatory response, 464f  
in innate immunity, 494  
mononuclear phagocytic (reticuloendothelial) system and, 460  
as phagocytes, 456, 457t, 494, 568  
as second line of defense, 452, 452f
- macular rashes, diseases that cause, 594b
- macules, 591, 592f
- mad cow disease (bovine spongiform encephalopathy), 19, 200, 395, 419t, 636f, 637
- magainins, 585



- “magic bullet” chemotherapies, 11–12, 499b, 559
- magnesium  
as cofactor, 115  
enzyme inhibition and, 118  
fluoride and, 118  
magnesium (Mg)  
atomic number/atomic weight, 27t  
electron configuration, 28t  
microbial requirements, 158  
magnesium ( $Mg^{2+}$ ), 115  
magnet-like  
inclusions(magnetosomes), 95, 95f  
magnetosomes, **95**  
*Magnetospirillum magnetobacterium*, magnetosomes of, 95, 95f  
magnification  
total, calculation of, 55–56  
by various microscopes, 58f  
major histocompatibility complex (MHC), 484f, **485**, 500f, **538–539**  
malachite green stain, 67, 70–71, 71t  
malaise, sense of, 408  
malaria, 17, 330, 348, 351–352, 352f, 356t, 364t, 413t, 447, 462, **656b**, **668–672**, 670f, 671f  
*Anopheles* mosquito as vector, 351–352, 352f, 364t, 414t, 669  
artemisinin to treat, 577  
chloroquine to treat, 577, 671  
disease reservoirs for, 413t  
DNA vaccines and, 258  
global warming and, 418  
incidence in U.S., 669–670, 671f  
incubation period, 431t  
Malarone to treat, 671  
“malignant”, *P. falciparum* and, 670  
mefloquine (Lariam) to prevent, 571, 671  
mefloquine (Lariam) to treat, 562t  
as notifiable infectious disease, 424t  
*Plasmodium* causing, 351–352, 352f, 356t, 656b, 669  
portals of entry, 431t  
prevention and, 672  
prophylaxis for, 571, 671  
quinine to treat, 12, 571, 671  
red blood cells in, 670, 671f  
sickle cell disease and, 410  
transmission due to, 413t, 669  
treatments for, 671  
vaccine development and, 351, 509, 670–671  
*Malassezia*, 340t, 404t, 591  
*Malassezia furfur*, as normal microbiota of skin, 404t, 591  
malathion (Ovide), 608  
male reproductive system, **750**, 751f  
malic acid, 126f, 147f  
malignant melanoma, alpha interferon to treat, 473  
malactic fermentation, **806**  
malt, **806**  
malt extract, fermentation and, 134t  
malting, **806**  
mammalian cells in culture  
advantages for making foreign gene products, 256–257  
cystic fibrosis and, 259t  
genetically modified colony-stimulating factor (CSF) and, 257  
genetically modified erythropoietin (EPO) and, 259t  
genetically modified interferons and, 259t  
genetically modified monoclonal antibodies and, 259t  
genetically modified to host viruses, 256–257  
mammals, domestic or wild, as disease reservoirs, 413t  
manganese, as cofactor, 115  
mannan, 99  
*Mannheimia haemolytica*, 282b  
mannitol, biochemical tests and, 137, 137f  
mannitol-salt agar, 165, 166f, 423b  
mannose, as receptor on host cells, 432  
mannose-binding lectin (MBL), 460, **469**, 470f  
Mantoux test for tuberculosis, 690  
mapping of genes. *See* gene mapping  
maraviroc, 553, 576  
Marburg virus (green monkey virus), **19**, **666**, **667b**  
as filovirus, 378t, 390f  
as potential biological weapon, 654b  
Marek’s disease vaccine, 543  
margination, 464f, **465**  
Margulis, Lynn, 10f, 105  
marine algae, toxic, 346–347  
marine mammals  
cetacean morbillivirus (CM) and, 282b  
killed by toxic algae, 344  
mortality rates and veterinary microbiology, 282b  
marine microbiota, 2, 303  
fluorescent in situ studies and, 292, 303  
marker genes  
in blue-white screening technique, 255, 255f  
uses for, 249, 249f  
Marshall, Barry, 13t  
mast cells  
in complement activation, 467, 468f  
in hypersensitivity reactions, **529**, 529f  
IgE antibodies and, 481  
recruited by antimicrobial proteins (AMPs), 473  
*Mastadenovirus*, 372f, 377t, 387f, 445t  
cytopathic effects of, 445t  
matrix, mitochondrial, **103**, 104f  
mattress sterilization, 201  
maturation inhibitors, **553**  
maturation stage in viral  
multiplication, 382f, **383**, 387f, 389f, **391–392**, 392f  
maximum growth temperature, **154**, 154f  
Mayer, Adolf, 369  
MBC (minimal bactericidal concentration), 578, 578f  
MBL (mannose-binding lectin), 460, **469**, 470f  
McCarty, Maclyn, 10f, 15, 47, 232  
McClintock, Barbara, 10f, 237  
MDR-TB (multi-drug resistant tuberculosis), **18**, **691**  
ME (myalgic encephalomyelitis), **639**  
measles, German. *See* rubella  
Measles Initiative, 510b  
measles (rubeola), 594b, **603–604**, 604f  
as a world health problem, 510b  
incubation period, 431t  
macular rash caused by, 594b  
mortality rates, vaccination and, 510b  
as notifiable infectious disease, 424t  
as persistent viral infection, 394, 396t  
portals of entry, 430, 431t  
portals of exit, 446  
vaccine, 14, 506t, 507t, 510b, **603–604**  
measles virus (*Morbillivirus*), 378t, 603  
airborne transmission and, 413, 430, 431t  
causing subacute sclerosing panencephalitis (SSPE), 394, 396t  
cytopathic effects of, 445t  
incubation period, 431t  
portals of entry, 430, 431t  
as potential biological weapon, 654b  
vaccine, 14, 506t, 507t, 510b, **603–604**  
“measly” beef, 357  
measurement of microorganisms, 54  
metric units of length/U.S. equivalents, **54t**  
meat extracts, in complex culture media, 162, 163t  
meat products, fermentation and, 134t  
mebendazole, 566t, 577  
mechanical transmission of disease, by arthropods, **414**, 414f, 414t  
Medawar, Peter Brian, 13t  
mediators (chemical), in allergic reactions, 523–524, 524f  
medical discoveries, accidental, 12  
medical implants  
bacterial colonization on, 537b  
biofilms and, 17, 18f, 537b  
supercritical carbon dioxide to decontaminate, 199  
medical microbiology, 70, 283, 314  
medicine  
antibiotics overuse/misuse and, 237  
importance of rDNA technology to, 258–259, 258f, 259t  
medium, light-bending ability of, 58  
medulla, of lichen, **342**, 343f  
mefloquine (Lariam), 562t, 577, 664  
megacolon, 668  
megascophagus, 668  
meiosis, 100t, 102  
in algae, 345f  
fungal, **335**, 338f, 339f  
in plasmodial slime mold, 355f  
melanin, genetically modified, 257  
melanoma  
genetically modified interferons to treat, 259t  
malignant, alpha interferon to treat, 473  
melarsoprol, to treat African trypanosomiasis, 633  
melioidosis, 278, 307, **697**, **706b**  
Mello, Craig, 13t  
membrane attack complex (MAC), 438f, 462, **467**, 468f, 470  
MAC-resistant bacteria, 467  
membrane-bound ribosomes, 101  
membrane-disrupting toxins, **438–439**, 441t  
membrane-enclosed organelles, in eukaryotes/eukaryotic cells vs. prokaryotes, 76  
membrane filters, **188**, 188f  
membrane, inner. *See* plasma (cytoplasmic) membrane  
membrane, outer, 85f, 87t, 88, 89f  
membrane ruffling, 435, 435f  
memory (anamnesic) response (secondary response), **497**, 497f  
memory cells, **485**, 486f, 505  
of B cells, **485**, 486f, 497, 497f  
delayed hypersensitivity reactions and, 535  
immunological, **497**, 497f  
of T cells, 489  
meninges, 616, 617f  
inflammation of. *See* meningitis  
meningitis, **616**, **623b**  
in AIDS patients, 626–627  
bacterial, **617–621**, **623b**  
*Haemophilus influenzae* (HiB), 312, 433, 618  
*Listeria monocytogenes*, 619–621. *See also* *Listeria monocytogenes*  
*Neisseria meningitidis*, 618–619. *See also* meningococcal meningitis  
*Streptococcus pneumoniae*, 619  
Clinical Case, 300b, 317b, 318b, 320b, 324b  
cryptococcosis and, 626–627  
*Cryptococcus neoformans* causing, 445  
diagnosis of, 300b, 619, 620f, 623b  
gonorrheal, 748  
method of transmission, 623b  
respiratory tract as portal of entry, 623b  
treatments for, 619, 623b  
vaccine, 506t, 507t, 612, 623b  
viral, **617–618**  
meningococcal meningitis, **618–619**, 618f, **623b**  
endotoxins and, 439, 442t, 613  
*Neisseria meningitidis* causing, 307, 404, 424t, 433, 441, 442t, 618–619, 618f, **623b**  
as notifiable infectious disease, 424t  
portal of entry, 618  
portal of exit, 446  
vaccine, 506t, 507t  
Xigris to treat, 640  
meningococcus, **613**  
serotypes of, 613  
meningoencephalitis, 356t, **616**  
Clinical Case, 616b, 621b, 622b, 635b, 637b, 639b  
primary amebic, **623b**, **629**, 629f



- differential interference contrast, 59, 61f, 65t  
 fluorescence, 59, 61f, 65t  
 phase-contrast, 57, 60f, 66t  
 magnification ranges (Foundation Figure), 58f  
 path of light in, 55, 55f, 59f, 60f  
 scanned-probe, 58f, 64, 64f, 67t  
 scanning acoustic (SAM), 63, 63f, 67t  
 scanning tunneling (STM), 64, 64f, 67t  
 specimen size and, 58f  
 summary table (features/typical image/uses), 65t-67t  
 two-photon (TPM), 60, 62f, 67t  
 ultraviolet light and, 59, 61f, 65t  
 units of measurements for, 54, 54t  
 to view inside cells/specimens, 6, 62f, 63f, 64, 65t, 66t
- microscopic count of bacteria, 173, 175, 175f
- Microspora, 275f
- Microsporidia, 337, 337f
- microsporidiosis, 337f
- Microsporium*, 340t
- cutaneous mycosis and, 597b, 605-606
- reservoirs/transmission method, 413t
- microtiter plates, 515, 516f, 520, 523f
- microtubules, 98f, 99, 99f, 100t, 101 of centrioles, 104-105  
 microsporidial protozoa and, 348
- microwaves, 190
- mildew  
 copper compounds to prevent, 195-196  
 damp shower curtains and, 189  
 mercurials to control in paints, 195
- milk  
 breast, IgA antibodies in, 480, 481  
 contaminated, *Coxiella burnetii* and, 309  
 counting number of bacteria in, 173, 175f  
 dairy cow, bovine growth hormone and, 266, 267t  
 fermentation and, 134t  
 food allergies and, 525  
 lactic acid fermentation and, 135t  
*Listeria* in, flow cytometry to detect, 288-289  
 pasteurization and, 8, 187-188, 191t  
 millimeter (mm), 54t
- Milstein, César, 13t, 512
- minimal bactericidal concentration (MBC), 578-579, 579f
- Minimal Genome Project, 261
- minimal inhibitory concentration (MIC), 283f, 578, 579f
- minimum growth temperature, 154, 154f
- mining industry, microbes used in, 245
- minocycline, 571
- miRNAs (microRNAs), 222-223, 223f, 258, 260
- miscarriage, induced by endotoxins, 440
- missense mutation, 225, 225f
- Mitchell, Peter, 10f
- mites, 364t  
 ivermectin effective against, 572
- mitochondria/mitochondrion, 98f, 101, 103, 104f  
 electron transport chain (system) and, 129  
 eukaryotes that lack, 337  
 origin of, 274f, 326
- mitosis, 100t, 102, 276t  
 in algae, 342, 345f  
 in diatoms, 343f  
 fungal, 336f
- mitotic spindle, 105
- Mixotricha* (protozoan), that lives in termite hindgut, 106b
- μm (micrometer), 54  
 metric/U.S. equivalent, 54t
- mm (millimeter), metric/U.S. equivalent, 54t
- MMR vaccine, 506, 507t, 511, 598
- MMWR (*Morbidity and Mortality Weekly Report*), 422
- moderate-temperature-loving microbes (mesophiles), 154, 154f
- moist heat sterilization, 185-187, 186f, 191t
- molasses, fermentation and, 134t
- molds, 2, 4, 5f, 332-333, 332f  
 acidic conditions and growth of, 189, 341  
 actinomycetes and, 319  
 as aerobic organisms, 333  
 bacterial food spoilage vs. damage done by, 341  
 bread, 5f, 197, 335f, 337  
 chemical food preservatives and, 197, 202t  
 as eukaryotes, 6, 75  
 filamentous, plate counts and, 176-177  
 growing in homes, allergic responses and, 445  
 included in Kingdom Fungi, 280  
 low moisture and growth of, 189, 341  
*mucor*, 5f  
 osmotic pressure and growth of, 189  
 penicillin discovery and, 12  
 pH and growth of, 156  
 saprophytic, 337  
 slime, 4. *See also* slime molds
- mole (unit of measure), 31
- molecular biology, 15
- molecular clock, 277
- molecular genetics  
 cloning procedures of, 247  
 ethical issues and, 267
- molecular oxygen (O<sub>2</sub>), 33, 135t
- molecular weight, 31
- molecules, 26  
 covalent bonds and, 30, 30f  
 heat absorption by, 34  
 how atoms form, 27-31  
 hydrogen bonds and, 30-31, 31f, 31t  
 important biological, 33-48. *See also* specific molecules
- inorganic, 33-36  
 ionic bonds and, 29-30, 29f
- macromolecules, 34, 38  
 nonpolar, of lipids, 38-39  
 organic, 36-48  
 polar, 33-34
- Molluscipoxvirus*, 377t
- mollusks  
 domoic acid intoxication and, 346  
 paralytic shellfish poisoning (PSP) and, 346, 356t, 446  
 red tides and, 446
- Monarch butterflies, 266
- monkeypox, 596b, 601  
 as orthopoxvirus, 596  
 as potential biological weapons, 654b  
 rash caused by, 596b  
 transmission from animals to humans and, 601
- monkeypox virus*, 596b, 601
- monkeys  
 as disease reservoirs, 413t, 659, 667b  
 green, AIDS in, 377  
 simian immunodeficiency virus and, 545
- monobactam antibiotics, 562t, 569
- monoclonal antibodies (Mabs), 512-514, 513f, 522  
 chimeric, 514  
 in diagnostics/medical therapies, 259t, 512, 513f, 514, 522  
 discovery of, 512  
 fully human, 514  
 in home pregnancy tests, 520, 522f  
 humanized, 514  
 hybridoma and, 512, 513f  
 industrial fermentation used in making, 802  
 as tool for delivering cancer therapies, 522, 543  
 to treat arthritis, 538  
 to treat immunological tissue rejection, 544b  
 to treat viral infection, 385
- monocytes, 456, 457t  
 developing into phagocytic macrophages, 456, 460  
 in inflammatory response, 461f
- Monod, Jacques, 10f, 15, 219
- monoecious helminths, 356
- monomers, 37  
 antibody, 482, 482f, 483t
- monomorphic bacteria, 78
- mononuclear phagocytic (reticuloendothelial) system, 460, 644
- mononucleosis, infectious, 377t
- monosaccharides, 37
- monotrichous flagella, 80f, 81
- Montagnier, Luc, 13t
- Montagu, Mary, 505
- Moraxella catarrhalis*, otitis media caused by, 685
- Moraxella* genus/spp., 301t, 309
- Moraxella lacunata*, conjunctivitis and, 309
- Morbidity and Mortality Weekly Report* (MMWR), 422
- morbidity rate, 422
- Morbillivirus* (measles virus), 378t  
 persistent viral infections and, 394
- mordant, 68, 71t, 86
- morphology of bacteria, 77-78, 77f, 78f  
 in identification/classification, 284
- mortality, influenza-associated  
 pediatric, as notifiable infectious disease, 424t
- mortality rate, 422
- mosaic disease of cauliflower, 396t
- mosaic disease of tobacco, 14, 369, 370
- mosquitos, 356t, 363f, 364t  
 as arthropods, 331f, 363f, 364t  
*Culex*, transmitting West Nile virus, 631  
 diseases transmitted by, 356t, 364t, 413t  
 encephalitis caused by, 630-632, 632f  
 as vectors, 363, 364t, 365  
 viruses transmitted by. *See* arboviruses
- mosses, as eukarya, 6
- most probable number (MPN)  
 method, 172, 174f
- motility, 81  
 of bacteria, 81-82, 82f  
 gliding, 83  
 pili and, 83-84  
 of spirochetes, 82-83, 83f, 325, 325f  
 twitching, 83
- mouse cells, genetically modified  
 products produced in, 259t
- mouse mammary tumor virus, 392
- mouth diseases  
 dental caries (tooth decay), 713-715, 713f, 714f, 716b  
 gingivitis, 709, 710b  
*Haemophilus* and, 312  
 normal microbiota of, 17f, 312, 326, 404t  
 periodontal disease, 709, 709f, 710b  
 periodontitis, 709
- mouthwashes, 196
- movement, proteins and, 41
- movement patterns of bacteria, 81-82, 82f
- moxifloxacin, 572
- MPN (most probable number)  
 method, 172, 174f
- mRNA. *See* messenger RNA
- MRSA (methicillin-resistant *Staphylococcus aureus*), 1, 18, 568  
 cellulitis caused by, 598b  
 Clinical Case, 2b, 17b, 19b, 20b, 21b  
 community-associated strains, 21b, 581, 598b  
 daptomycin to treat, 572  
 emerging infectious diseases and, 18, 419t  
 health-care associated strains and, 423b, 581, 597b  
 hemolysis patients and, 423b  
 linezolid to treat, 572  
 mortality rate for, 581  
 nosocomial infections and, 423b, 581  
 PCR testing to rapidly isolate, 423b, 581  
 platensimycin developed in response to, 566



- professional athletes and, 598b  
superantigens and, 593  
superbugs and, 580  
tigecycline (Tygacil) developed in response to, 565  
USA100, USA 300 strains, 423b  
vancomycin and, 569, 598b
- MS. *See* multiple sclerosis
- mucocutaneous mycoses, 340t
- Mucor*, 5f, 340t, 341
- Mucor indicus*, 334f
- mucormycosis, 341
- mucosa-associated lymphoid tissue, 490b
- mucous membranes (mucosa), 453–455, 590  
as barrier to pathogens, 453, 474t, 590  
broken, susceptibility to infections, 416, 417t, 451  
ciliated, of lower respiratory tract, 675, 676f  
as first line of defense, 452f, 453–455, 474t  
of gastrointestinal tract, 453, 454  
of genitourinary tract, 453, 455  
*Haemophilus* normal occupants of, 312  
IgA antibodies and, 483t  
of nose, 453  
as portals of entry, 430, 431t, 447f  
as portals of exit, 446–447, 447f  
of respiratory tract, 453, 454  
structure of, 590  
*Treponema pallidum* and, 453–454
- mucus, 453, 454  
cervical, 455  
cervical, antimicrobial activity of, 455  
ciliary escalator and, 454, 454f  
IgA antibodies in, 480  
lysozyme in, 88, 455
- mules, reported cases of rabies in, 630f
- Mullis, Kary B., 13t
- multi-drug resistant tuberculosis (MDR-TB), 18, 691
- multicellular animal parasites, 5–6
- multiple sclerosis (MS), 259t, 470, 538  
beta interferon (Betaferon) to treat, 473  
Epstein-Barr virus and, 533, 664  
HLA typing to determine susceptibility, 539t  
interleukin-12 to treat, 499b  
monoclonal antibodies to treat, 522
- multiplication of viruses. *See* viral multiplication
- mummies, DNA extraction and, 263
- mumps, 727–728, 727f, 736b
- mumps virus (*Rubulavirus*), 378t  
incubation period, 431t  
as notifiable infectious disease, 424t  
portals of entry, 431t  
portals of exit, 446  
vaccine, 14, 506t, 507t, 721
- municipal chlorination, household bleach equivalent in emergencies, 194
- municipal waste (garbage), 781–782, 782f
- municipal water treatment systems, chloramines to disinfect, 194
- murein. *See* peptidoglycan
- murine leukemia virus-related viruses (MLV), 639
- murine (mouse) cells, 513f, 514
- muromonab-CD3 (Mab-CD3), 259t, 544b
- Murray, Joseph E., 13t
- Murray, Robert G.E., 273
- muscle contraction, proteins and, 41
- muscle contractions, uncontrollable, tetanus toxin causing, 439
- muscles, parasitic helminths and, 364t
- muscular dystrophy, Duchenne's, 16
- mushrooms, 4  
as eukarya, 6  
included in Kingdom Fungi, 280  
produced by Basidiomycota fungi, 338  
toxins produced by, 445
- mussels  
diatoms, neurologic disease outbreak and, 346  
paralytic shellfish poisoning (PSP) and, 344, 356t
- mutagenesis, site-directed, 247
- mutagens, 226–228  
Ames test and, 230–231, 230f  
as carcinogens, 230–231  
chemical, 226–227, 226f, 232  
experimental uses of, 228  
identifying, 228–231, 228f, 229f  
radiation, 227–228, 228f  
spontaneous rate of mutation and, 231
- mutations, 223–231  
acquired by West Nile virus, 220b  
antibiotic resistance and, 225, 228, 574, 577t  
beneficial, 223, 228  
Clinical case, 208b, 226b, 231b, 232b  
disadvantageous, 223–224  
evolution and, 228  
frameshift, 225, 225f  
frequency of, 228  
genotoxic chemicals, 231b, 232b  
HIV and, 545, 547  
horizontal gene transfers to other bacteria, 574, 577f, 583b  
identifying chemical carcinogens, 230–231, 230f, 232b  
identifying mutants, 228–230, 229f, 230f  
lethal, 223–224  
missense, 225, 225f  
molecular clock and, 277  
nonsense, 225, 225f  
point (base substitution), 224–225, 224f  
positive (direct) selection to identify, 231  
radiation and, 227  
random, 231, 429  
rate of, 228  
repair of, 227, 228f  
retroviruses and, 547  
selection methods to identify mutations, 229–230, 229f  
silent (neutral), 224  
spontaneous, 225  
types of, 224–225, 225f
- mutilin, 565t, 572
- mutualism, in lichens, 342
- mutualism in symbiotic relationships, 405, 405f
- myalgic encephalomyelitis (ME), 639
- myasthenia gravis, 537
- mycelia/mycelium, 4, 333, 333f, 335f, 336f, 337f
- mycelium. *See* mycelia/mycelium
- mycetoma, 320
- mycobacteria  
as aerobic, non-endospore-forming rods, 319  
antibiotics that inhibit, 562t, 569–570  
antimicrobials effective against, 201t  
filamentous growth and, 319  
mycolic acid in cell walls of, 88, 319, 433, 563  
pathogenicity of, 319  
quats ineffective against, 196  
rapidly-growing, 201b  
resistance to chemical biocides, 196, 198b, 200, 200f, 319  
slow-growing, 198b, 319  
identification tests, 142b, 203
- Mycobacterium abscessus* infection (Clinical Focus), 198b
- Mycobacterium avium*, 142b  
interleukin-12 to treat, 499b
- Mycobacterium avium-intracellulare*, 550t, 685
- Mycobacterium bovis*, 70f, 142b, 685
- Mycobacterium* genus/spp., 302t, 319  
antibiotics that inhibit, 562t, 569–570  
antimicrobials effective against, 201t  
cell walls of, 40, 69, 70f, 87–88, 302t, 319  
diseases caused by, 319  
G + C content and, 314  
lipid inclusions of, 95
- Mycobacterium intracellulare*, 447f
- Mycobacterium leprae*  
acid-fast stain to identify, 69  
armadillos used to culture, 163, 625  
cultivation and, 163, 406  
grows in peripheral nervous system, skin cells, 625  
leprosy caused by, 406, 625–626, 632b  
as slow growing mycobacteria, 201b
- Mycobacterium tuberculosis*, 682–685, 682f, 683f  
acid-fast stain to identify, 69  
AIDS-associated, 550t  
antibiotics to treat, 563, 690–691  
biocidal effectiveness tests especially developed for, 200  
can survive/multiply in phagocytes, 433, 462  
desiccation resistance and, 189  
diseases caused by (other than TB), 407  
disinfectants and, 202  
fluorochrome auramine O to stain, 59  
found in Egyptian mummies, 6  
incubation period, 431t
- Koch's experiments with, 406  
lipid-rich cell wall of, 40  
pathogenesis of, 688–690, 689f  
portals of entry, 430, 431t  
qPCR test to rapidly detect, 251  
resistance to chemical biocides and, 200  
skin test for, 535, 690  
as slow growing mycobacteria, 198b  
urease test to identify, 142b  
virulence and, 433
- Mycobacterium ulcerans*, Buruli ulcer caused by, 594, 597b, 599
- mycolactone toxin, 599
- mycolic acid (waxy lipid), 88, 319, 433  
antibiotics that inhibit synthesis of, 563  
of *Mycobacterium tuberculosis*, virulence and, 433
- mycology, 14, 332
- mycophenolate, 542
- Mycoplasma capricolum*, 261
- Mycoplasma* genus/spp., 87, 301t, 317–318, 318f  
culture media and, 318  
degenerative evolution and, 318  
G + C content of, 314  
plasma membrane uniqueness, 87, 89  
viruses and, 87, 318
- Mycoplasma hominis*, 758
- Mycoplasma mycoides*, 261
- Mycoplasma pneumoniae*, 318, 318f
- mycoplasmal pneumonia, 318, 318f, 565, 693–694, 694f, 695b  
tetracyclines to treat, 565
- mycoplasmas, 319–320, 319f  
G + C ratio of, 314  
sterols in plasma membrane of, 41, 87, 89
- Mycoplasmatales, 301t, 317–318
- mycorrhizae (symbiotic fungi), 332, 773, 774f
- mycoses (fungal infections), 339–341, 340t, 605  
Clinical Case, 332b, 339b, 341b, 342b  
cutaneous, 340–341, 340t, 605–607, 606f  
emerging (*Cryptococcus gattii*), 342b  
increasing rates of, 14  
opportunistic, 340–341  
subcutaneous, 606  
systemic, 339
- mycosis, 339, 605. *See also* mycoses
- mycotoxins, 445, 735
- myeloma cells, in monoclonal antibody production, 513f
- myelomas, 512
- myxobacteria, 313  
fruiting body of, 56b, 56f, 313, 313f  
gliding motility of, 56b, 83, 313, 313f
- Myxococcales, 301t, 313, 313f
- Myxococcus fulvus*, 313, 313f
- Myxococcus* genus/spp., 301t, 313, 313f
- Myxococcus xanthus*, 56b, 56f, 313, 313f
- myxospores, 313, 313f
- N  
N-acetylglucosamine (NAG), 84, 84f, 85f  
chitin and, 99

- N-acetylmuramic acid (NAM), 84, 84f, 85f
- N-acetylglucosaminuronic acid, 87
- NA (neuraminidase) proteins, 371
- spikes of influenza virus, 692–693, 692f
- subtypes of influenza A viruses, 374–375b
- NAATs (nucleic acid amplification tests), **290**
- NAD<sup>+</sup>, **114**, 115t
- in biological oxidation, 120, 121f
- as electron carrier, 141f
- in electron transport chain, 121, 127f, 127f
- in fermentation, 130–133, 133f
- in Krebs Cycle, 125, 126f
- in oxidative phosphorylation, 120–121
- NADH
- in alcohol fermentation, 131, 133, 133f
- in biological oxidation, 120, 121f
- in electron transport chain, 120, 127f, 127f
- in Krebs cycle, 125–127, 126f
- in photosynthesis, 138, 139f
- redox reaction and, 120, 121f
- NADP<sup>+</sup>, **114**
- in Calvin-Benson cycle, 140f
- as coenzyme in cellular metabolism, 114
- as electron carrier, 141f
- in photosynthesis, 138, 139f
- NADPH
- in Calvin-Benson cycle, 140f
- in fermentation, 131
- in neutrophils (Clinical Case), 463b, 466b, 472b, 473b
- in photophosphorylation, 121, 138, 139f
- in photosynthesis, 138, 139f
- Naegleria fowleri* (amoeba), 356t, 615f, 623b, **634**–635, 635b, 635f
- naftifine, 566t, 574
- NAG (N-acetylglucosamine), 84, 84f, 85f
- chitin and, 99
- nails (finger/toe), cutaneous mycoses and, 340
- naked DNA
- transformation process and, 232, 251
- vaccines and, 503
- naked RNA, viroids and, 396–397
- nalidixic acid, 565t, 572, 585
- NAM (N-acetylmuramic acid), 84, 84f, 85f, 87
- names for living organisms. *See* scientific nomenclature
- nanobacteria, **326**
- nanometer (nm), **54**, 54t
- nanons, **327**
- nanospheres, 263, 263f
- nanotechnology, **263**, 263f
- naphthoquinones, 115t
- narrow spectrum antibiotics, **560**–561, 562t
- nasal passages
- normal microbiota of, 1, 1f, 165, 404t, 588
- secretions, staphylococci in, 316, 588
- nasal spray for influenza vaccine, 506
- nasolacrimal ducts, 454f
- nasopharyngeal cancer, Epstein-Barr virus and, 664
- Natamycin (pimaricin), 197
- Nathans, Daniel, 10f
- National Institute of Allergy and Infectious Diseases (NIAID), interleukin-12 research by, 499b
- natural classification systems, 273, 277
- natural killer (NK) cells, 457t, **458**, 474t, **495**, 496t
- natural penicillins, **564t**, **567**, 567f
- natural recombination of DNA in microbes
- competence and, 233, 251
- conjugation and, 236, 251
- occurrence of, 245
- transformation and, in genetic engineering, **251**
- natural selection, 239
- antibiotic resistance and, 583b
- artificial selection vs., 247
- Charles Darwin and, 273
- coevolution and, 429
- definition of, 430
- evolution and, 239, 273, 429
- horizontal gene transfer and, **232**, 583b
- resistance factors of bacteria and, 235–237
- Necator americanus*, 361, 364t, 740b, 741
- necrosis, **646**
- necrotizing fasciitis, 286, 317, 423b, 434b, **595**–596, 595f, 597b
- due to leukocidin toxin MRSA-infection, 423b
- rash caused by, 59b, 434f, 597b
- streptococcus pyogenes* streptokinase causing, 434b, 597b
- Needham, John, 7
- needles
- AIDS, hepatitis B transmitted by, 447
- nosocomial infections and, 416
- negative (indirect) selection identify mutant cells, **229**–230, 230f
- negative staining, **67**, 70, 70f, 71t
- bacterial capsules and, 70, 70f, 71t, 80
- bacterial flagella and, 70f, 71t
- electron microscopes and, 62
- of *Mastadenovirus*, 387f
- Neisser, Max, 10f
- Neisseria* genus/spp., 300t, **307**
- antibiotic resistance, susceptibility testing, 751b
- genetic transformation natural occurring in, 233
- as normal microbiota of mouth, throat, 404t
- penicillinase-producing plasmid acquired from *Streptococcus*, 237
- Neisseria gonorrhoeae*, 307, 307f, 747–750, 750f
- adhesins to host cells and, 433
- antigenic variation in, 435, 749
- complement system evasion by, 470
- desiccation resistance and, 189
- directly damaging host cells, 436
- fimbriae, colonization, and disease, 83
- fluoroquinolone-resistant, 750, 751b
- gonorrhea caused by, 307, **747**. *See also* gonorrhea
- grows inside human epithelial cells, leukocytes, 433
- IgA proteases and, 435
- incubation period, 431t, 748
- inherited susceptibility to, 470
- ophthalmia neonatorum and, **610**, **748**–749
- oxidase test to identify, 137
- pelvic inflammatory disease caused by, 758
- portals of entry, 430, 431t, 749
- twitching motility of, 83
- Neisseria meningitidis*, 307
- as endotoxin producer, 441
- IgA proteases and, 435
- inherited susceptibility to, 470
- iron source for, 473
- meningitis caused by, 307, 424t, 433, 441, 442t, 612, **613**, 613f, **623b**
- as opportunistic pathogen, 405–406
- vaccine, 506t
- Neisseria meningitis*. *See* meningococcal meningitis
- Neisseria* spp., 300t
- Nematoda, 189, 355, **360**–363, 364t. *See also* nematodes
- nematodes (roundworms), 189, 355, **360**–363, 362f, 364t
- freezing temperatures and, 189
- ivermectin effective against, 572
- neomycin, 565t, **570**
- produced by *Streptomyces fradiae*, 560t
- neonatal herpes, **764**
- neonatal sepsis, *Streptococcus agalactiae* and, 317, 320b, 324b, 647
- nephritis, 407
- nervous system
- blood-brain barrier and, **616**, 617f
- microbial diseases, 615–642
- bacterial, 617–626, **623b**
- fungal, **623b**, 632–633
- prions, **632b**, 636–637
- protozoan, **623b**, 629f, 633–635
- viral, **623b**, 626–632, **628b**, **632b**
- pathogenic invasion routes, 616, 617f
- structure/function of, 616–617, 616f, 617f
- neuraminidase (N) proteins
- influenza A virus subtypes and, 374–375b
- to treat influenza, 570
- neuraminidase (NA) spikes of *Influenzavirus*, 692–693, 692f
- neurocysticercosis, 361t, 364t, **739**
- neurological diseases, 225, 225f, 343, 395
- caused by diatoms, 343
- prions causing, 395
- spongiform encephalopathies, 200, 395, 630f
- neurosyphilis, 761
- neurotoxins, 435, 439, 440, 443
- algae produced, 343, 344, 346, 446
- fungi produced, 445
- plankton produced, 346–347
- plasmids and *Clostridium tetani*, 235
- neutral (silent) mutations, 226–227
- neutralization, **517**
- neutralization reactions, 487, **488**, 488f, **517**, 518f
- cytopathic effects of viruses and, 443, 512
- viral hemagglutination inhibition test, **517**, 518f
- neutrons, **26**, 26f
- neutrophils, **456**, 457t, 463b
- antimicrobial peptides and, 473
- cathelicidins produced by, 473
- defensins produced by, 473
- in fungal infections, 463b, 466b, 472b, 473b
- gamma interferon and, 471
- in inflammatory response, 464f
- oxidase-related genetic mutation, 466b
- as second line of defense, 452f
- staining and, 456
- nevirapine, 575
- newborn diseases
- candidiasis occurring in, 341
- IgG antibodies and, 483t
- neonatal sepsis, 317, 320b, 324b, 647
- silver nitrate solutions and, 195, 202t
- skin infections in, 196, 196f
- Newcastle disease in chickens, 378t, 705b
- NGU. *See* nongonococcal urethritis
- niacin (nicotinic acid), 115t
- NIAID (National Institute of Allergy and Infectious Diseases), interleukin-12 research by, 499b
- nickel allergy, 530
- niclosamide, 562t, 566t, 577
- nicotinamide adenine dinucleotide. *See* NAD<sup>+</sup>
- nicotinamide adenine dinucleotide phosphate. *See* NADP<sup>+</sup>
- nicotinic acid (niacin), 115t
- Nightingale, Florence, 420
- nigrosin dye, 67
- NIH (National Institutes of Health), priorities (re: emerging infectious diseases), 418
- 9 + 0 array microtubules, 104–105
- 9 + 2 array microtubules, 99, 99f
- Nipah virus
- as a biological weapon, 654b
- emerging infectious diseases and, 419t
- nisin, 197, 578
- nitazoxanide, 566t, 577, 737
- nitrate, **197**, 202t. *See also* nitrite
- anaerobic respiration and, 130, 135t
- as food preservatives, 197, 202t
- importance to agriculture, 305
- Pseudomonas* bacteria and nitrogen fertilizers, 309
- nitrate reduction test, 142b
- nitric oxide, 462
- nitrification, 305, 776f, 777
- nitrifying archaea, 326
- nitrifying bacteria, 95, 300t, 301t, 305, 771
- nitrite gloves, 531
- nitrite, **197**, 202t. *See also* nitrate
- anaerobic respiration and, 130, 135t
- as energy source, 143, 305
- as food preservatives, 197, 202t

- Nitrobacter* genus/spp., 143, 300*t*, **305**, 770*f*, 771
- nitroblue tetrazolium (NBT) test, 463*b*
- nitrocellulose filters, 256*f*, 263*f*
- nitrogen cycle, **776–779**, 776*f*
- anaerobic respiration and, 130
- nitrogen fixation, **158**, **776**, 776*f*
- alphaproteobacteria and, 300*t*, 303–304
  - Azotobacter* and *Azomonas* used to demonstrate, 309
  - genetically modified plants and, 266, 267*t*
- nitrogen-fixing bacteria, 300*t*, 303–304, 305, 309, 314, 314*f*, 320–321, 777–778
- symbiotic, 777–779
- nitrogen (N)
- anaerobic respiration and, 130, 135*t*
  - atmospheric, life and, 304
  - cyanobacteria and, 15, 158
  - electronic configuration, 28*t*
  - microbial growth requirements, 158
  - in organic compounds, 36
  - soil pseudomonads and, 309
  - sources of, 158
  - symbol/atomic number/atomic weight, 27*t*
- nitrogenous bases
- changes in, 223–224. *See also* mutations
  - normal, vs. nucleoside analogs, 226–227, 227*f*
- nitrosamines, **197**
- Nitrosomonadales, 301*t*
- Nitrosomonas* genus/spp., 143, 301*t*, **305**
- nitrous acid, as mutagenic chemical, 226, 226*f*
- nitrous oxide, anaerobic respiration and, 130
- Nix (lice remedy), 608
- NK cells. *See* natural killer (NK) cells
- nm (nanometer), **54**
- metric/U.S. equivalent, 54*t*
- Nobel prizes in microbiology, 13*t*
- first prize awarded, 477
- Nocardia asteroides*, pulmonary infection caused by, 320
- Nocardia* genus/spp., 302*t*, 318, **320**
- acid-fast stains to identify, 69, 88
  - actinomycetes informal name for, 318–319
  - mycolic acid in cell walls of, 88
- nodular cystic acne, **594**, 595*f*
- nodular cystic (severe) acne, **600**, 600*f*
- norfloxacin, 565*t*, 572
- nomenclature
- binomial, **278**
  - scientific, 2–3, 4*t*, 278
- non-nucleoside agents, **575**
- non nucleoside reverse transcriptase inhibitors, 548
- nonbullous impetigo, 593
- noncommunicable diseases, **408**
- noncompetitive inhibitors of enzymes, **118**, 118*f*
- noncyclic photophosphorylation, **138**, 139*f*
- noncytotoxic effects of viruses, vs. cytotoxic effects, 443
- nonenveloped viruses, **371**, 372*f*, 373, 377*t*, 378*t*, 388*t*
- alcohol-based disinfectants and, 195, 202*t*
  - biocidal resistance and, 197*b*, 200, 200*f*
  - double-stranded RNA, 378*t*
  - hepatitis A, 392*b*
  - maturation stage in, 392
  - release stage in, 392
  - single-stranded RNA, 377*t*, 378*t*, 388*t*
- nongonococcal urethritis (NGU), 322, 462, 757–758, **767*b***
- nonionizing radiation, **190**, 190*f*, 191*t*
- nonpolar molecules of lipids, 38–39
- nonpolar tails of phospholipids, 40, 40*f*, 89, 89*f*
- nonproteobacteria gram-negative bacteria, 302*t*, **320–322**
- nonself vs. self recognition, 479, 492–493, 494, 500*f*
- autoimmune diseases and, 536–538
  - hyperacute rejection and, 536
  - immune system tolerance of fetus and, 534–535
  - major histocompatibility complex (MHC) and, 485, 486, **533–534**
  - thymic selection and, 486, 532
  - transplant rejection and, 534–535
- nonsense codons (stop codons), 209, 215*f*, **216–218**, 216–217*f*
- nonsense mutation, **225**, 225*f*
- nonspecific urethritis (NSU), **750–751**, **761*f***
- nonsulfur bacteria, defined, 324
- nontyphoidal salmonellae*, 719
- norfloxacin, 572
- normal microbiota/flora, 16–17, 17*f*, **402–405**, 403*f*, 404*t*, **455–456**
- antibiotics and, 403–405, 555
  - by body region, **404*t***
  - digestive, 712–713
  - reproductive, 751
  - respiratory, 682
  - skin, 452*f*, 455–456, 590
  - tongue, 17*f*
  - urinary, 751
  - body's defenses and, 402–403, 452*f*, 455–456
  - factors that affect, 402–403
  - host relationships with, 403–405, 403*f*
  - innate immunity and, 452*f*, 455
  - protozoa part of, 348
  - symbiotic relationships and, 405, 405*f*
  - transient, 402
- Norovirus, 377*t*
- noroviruses, **735**, **736*b***
- outbreak recurrence (Clinical Case), 182*b*, 197*b*, 199*b*, 201*b*
  - outbreak traced via geonomics (Clinical Focus), 261, 265*b*
- North American blastomycosis (blastomycosis), **697**, **699*b***
- Norwalk virus, 735
- nose, normal microbiota of, 1, 1*f*, 165, 404*t*, 588
- Nosema*, 340*t*
- Nosema locustae*, 348
- nosocomial infections, **414–417**, 415*f*, 423*b*
- Acinetobacter baumannii* and, 309
- antibiotic Primaxin active against, 561
- antibiotic-resistant pathogens and, 414
- before aseptic surgery, 181
- biofilms and, 17, 18*f*, 161
- case history reports
- bacteremia, 423*b*
  - infection following steroid injection, 198*b*
- causes of, 414, 414*f*
- chain of transmission and, 414*f*, 416
- childbirth fever of mid-1800's, 11, 420
- compromised hosts and, 414*f*, **416**, 417*t*
- control measures to prevent, 417
- cost of, 582
- DNA fingerprinting to determine source, 289, 289*f*
- Enterobacter* and, 312
- Enterococcus faecalis* and, 317
- Enterococcus faecium* and, 317
- gram-negative microbes and, 415, 416*t*, 640
- gram-positive microbes and, 415, 416*t*
- immune systems responses to, 416
- invasive procedures/devices risks, 17, 18*f*, 416
- microbes involved in, 415, 416*t*
- opportunistic pathogens and, 405–406, 415, 416*t*
- principal body sites affected by, 416, 417*t*
- Pseudomonas* bacteria responsible for one in ten, 309
- rates of, 415, 416*t*, 417*t*
- secondary infections and, 415
- sepsis as, **639–641**, **649*b***
- Serratia marcescens* and, 311
- Staphylococcus aureus* and, 18, 316
- vancomycin-resistant enterococci (VRE) and, 419*t*, **563**, 583*b*, 640
- Notifiable Infectious Diseases (U.S. Public Health Service), **422**
- Novo Nordisk Biotech, 3*b*
- Noxafil (posaconazole), 574
- NRTIs (nucleoside reverse transcriptase inhibitors), 553
- NSU (nonspecific urethritis), **750–751**, **761*b***
- “nubiotics”, 579
- nuclear envelope, **101**, 102*f*, 103*f*
- of *Gemmata obscuriglobus*, 322*f*
- nuclear membrane, 100*t*
- nuclear pores, **101**, 102*f*
- nucleic acid amplification tests (NAATs), **290**
- nucleic acid hybridization studies, **290**, 291*f*, 292
- DNA chip technology, 292, 292*f*
  - DNA probes, 255, 256*f*, 290, 291*f*, 292, 517
  - fluorescent in situ hybridization, 292, 293*f*
  - in HIV testing, 545
  - ribotyping/rRNA sequencing, 292
  - Southern blotting and, 261, 262*f*, 290, 291*f*, 292
- nucleic acid sequencing, West Nile virus tracking and, 220*b*
- nucleic acids, **44**, 46*f*, 47
- antimicrobial agents and, 184, 558, 558*f*, 561*f*, 562*t*, 567
  - in definition of life, 370
  - DNA, 46*f*, 47. *See also* DNA
  - gram-positive bacteria and, 314–320
  - RNA, 47, 47*f*. *See also* RNA
  - synthesis inhibition
    - by antimicrobial agents, 184
    - by antimicrobial drugs, 561*f*, 563, 565*t*, 572
  - vaccines, **508**
  - of viruses, 370, 371
- nucleobases (adenine/thymine/cytosine/guanine), 47, 48*f*, 49*f*, 208
- nucleoid
- of bacterial cells, 94
  - of *Gemmata obscuriglobus*, 322*f*
  - of prokaryotic cells, 79*f*, **94**
- nucleoli/nucleolus, 98*f*, **101**, 102*f*
- nucleoplasm, evolution and, 274*f*, 275, 277
- nucleoproteins, 44
- nucleoside analogs, **226–227**, 227*f*, 575
- AZT (azidothymidine) as, 227
  - zidovudine to treat HIV/AIDS, 575
- nucleoside reverse transcriptase inhibitors (NRTIs), 553
- nucleosides, **47**
- nucleoside analogs and, 226–227, 227*f*
  - nucleoside triphosphates, 212*f*, 213
- nucleosome, 101
- nucleotide analogs, tenofovir to treat HIV/AIDS, 575
- nucleotide excision repair, **227**, 228*f*
- defect, and inherited xeroderma pigmentosum, 228
- nucleotides, 46*f*, 47, **208**
- biosynthesis of, 145–146, 146*f*
  - in DNA replication, 210–215, 211*f*, 212*f*
  - mutations and, 223–231. *See also* mutations
- nucleobases (adenine/thymine/cytosine/guanine) and, 208
- nucleoside analogs and, 226–227, 227*f*
- porins and, 86
- RNA, 214*f*, 215
- nucleus
- of atoms, **26**, 26*f*
  - of eukaryotic cells, 76, 98*f*, 100*t*, **101–102**, 102*f*
  - as site of transcription, 220
  - in *Gemmata obscuriglobus* bacteria, 277, 322, 324*f*
  - prokaryotic cells and, 100*t*
- nude mice
- to culture leprosy bacillus, 544*f*, 619
  - transplant research and, 543, 544*f*
- numerical identification, **285**, 285*f*
- nurseries (hospital), effective disinfectants for, 196, 196*f*
- nursing home infections. *See* nosocomial infections
- nutrient agar, **163**, 163*t*
- nutrient broth, **163**
- nutrients, glucose's value as, 120
- nutritional requirements



- of algae, 5  
of archaea, 4  
of bacteria, 4  
of fungi, 4, 331f, 336  
microbes classified by patterns of,  
140–143, 141f  
of parasitic helminths, 355  
of protozoa, 5, 349  
nuts (tree-grown), food allergies  
and, 525
- O**  
O-phenylphenol, 192, 193f  
O polysaccharide, 85f, **86**, 470  
oak trees, *Phytophthora ramorum*  
infected by, 348  
objective lens of microscopes, **55–56**,  
55f, 60f  
obligate aerobes, **159**, 159t  
obligate anaerobes, **159**, 159t, 162  
culture media for, 167t  
obligate halophiles, **158**  
obligate intracellular bacteria, culture  
media and, 167  
obligate intracellular parasites, viruses  
as, 281  
obligately intracellular human  
pathogens, 300t, 301t  
obligatory intracellular parasites,  
viruses as, 281, **370**  
ocular lens (eyepiece) of microscopes,  
55–56, 55f, 60f  
OD (optical density)/absorbance,  
175, 176f  
oil, stored by diatoms, 345t, 348  
oil glands of skin  
antimicrobial properties, 404t  
sebum secreted by, 455, 474t, 590  
oil immersion objective lens, 56,  
57, 59f  
oil spills  
bacteria that degrade, 32b, 134  
bioremediation of, 16, 326, 781  
Okazaki fragments, 211t, 212f  
Old World flavivirus, introduced into  
New World, 220b  
oleic acid, 39f  
oligoadenylate synthetase, 471  
oligodynamic action, **195**, 195f  
olives, fermentation used in  
production of, 806  
omalizumab (Xolair), 530  
oncogenes, **393**, 442  
oncogenic viruses (oncoviruses),  
378t, **393**  
among DNA viruses, 393  
among RNA viruses, 393–394  
latent infection and, 394, 394f, 396t  
retroviruses as, 390  
oncolytic viruses, 371  
oncoviruses. *See* oncogenic viruses  
one-step growth curve (viral),  
381, 381f  
onychomycosis (tinea unguium), **606**  
oocysts, **352**  
of *Cryptosporidium*, 357b, 357f  
of *Toxoplasma gondii*, 352  
Oomycota (water molds), 345t,  
347–348, 347f  
oomycetes, 347–348  
as decomposers in fresh water,  
347, 347f  
as plant parasites, 347–348  
position in evolutionary tree, 275f  
OPA (ortho-phthalaldehyde), 197  
Opa (protein), **433**  
gonococcal bacteria and, 749  
*Neisseria gonorrhoeae* and, 435  
open-reading frames, 209  
operator, **221**, 221f, 222f  
operon, **221**, 221f, 222f  
operon model of gene expression,  
219–221, 221f, 222f  
operons  
inducible, **221**, 221f  
repressible, **221**, 222f  
ophthalmia neonatorum, 195, 202t,  
430, **609b**, **610**, 755–756  
ophthalmic cysticercosis, **739**, 739f  
opisthotonos, **621**, 621f  
opossums, as disease reservoirs,  
656b, 667  
opportunistic pathogens, 300t, 301t,  
302t, **405–406**  
commensal microbiota and, 456  
found in dolphins, 282b  
fungal infections, **340–341**, 340t  
opsonins, 462  
opsonization (immune adherence)  
in antigen-antibody binding,  
487–488, 488f  
in complement activation pathways,  
467, 468f  
microbial evasion of, 473  
phagocytosis and, 460, 462  
ophthalmic cysticercosis, **733**, 733f  
optical density/OD (absorbance),  
175, 176f  
optimum growth temperature, **154**, 154f  
oral candidiasis (thrush), 341, **601**,  
601f, **759**  
oral cavity bacteria, 302t, 713–714  
*Bacteroides*, 322  
*Fusobacterium*, 322, 324f  
spirochetes, 325, 325f  
*Streptococcus mutans*, 80, 135b,  
137b, 317, 432, 441,  
713–715, 714f  
oral groove, of *Chilomastix*, 350f  
oral rehydration therapy, for  
diarrhea, 717  
OraQuick test for HIV, 550  
orchitis, 727  
order (taxonomic), defined, **278**, 279f  
ore, bacteria used to extract, 245  
organelles, 98f, **101–105**. *See also*  
*specific structures*  
of apicomplexans, 351  
prokaryotic cells and, 100t, 276t  
organic compounds, **34**, 36–48  
chemistry of, 36–38, 36t  
most common elements found in,  
27t, 36  
structure of, 36–38, 36t  
organic growth factors, **160**, 162  
organic molecules. *See* organic  
compounds  
organisms, 272. *See also* microbes/  
microorganisms  
classification of, 277–281  
methods, 281–294  
evolutionary relationships among,  
273–275, 274f, 280f  
identification of, 281–294  
scientific nomenclature for, 2–3,  
4t, 278  
organotrophs (heterotrophs),  
**140–141**, 141f  
complex medium for growing, 163t  
*Ornithodoros* (tick), as vector for  
relapsing fever, 364t  
ornithosis (psittacosis), 322, 413t,  
**694**, **695b**  
Clinical Case, 681b, 696b, 697b,  
699b, 701b, 705b  
as notifiable infectious disease, 424t  
reservoirs/transmission methods, 413t  
orphan viruses, 390  
ortho-phthalaldehyde (OPA), 197  
orthoclone OKT3, 259t  
Orthomyxoviridae, **378t**  
orthomyxoviruses, 391  
*Orthopoxvirus*, 376f, 377t  
oseltamivir (Tamiflu), 566t, 575, 701  
osmium, used in staining of  
specimens, 62  
osmosis, 91f, **92–93**, 92f  
osmotic lysis, **88**, 93  
osmotic pressure, 92f, **93**  
to control microbial growth, 189, 191t  
microbial growth and, 156, 157f, 158  
most fungi resistant to, 336  
to preserve foods, 189  
osteoporosis, beta interferon  
(Actimmune) to treat, 473  
otitis externa (swimmer's ear), 597b, **598**  
otitis media, **685**, 685f, **686b**  
*Haemophilus influenzae* causing,  
613, 685  
*Moraxella catarrhalis* causing, 685  
*Streptococcal pneumoniae* causing,  
614, 685  
*Streptococcal pyogenes* caused by, 685  
out-of-phase light rays, 57  
outer membrane, 85f, 87t, 88, 89f  
ovarian cancer, genetically modified  
Taxol used to treat, 259t  
ovaries, 750, 750f  
Ovide (malathion), 608  
oxacillin, **564t**, 567f, **568**  
oxalate decarboxylase, 115t  
oxaloacetic acid, 145f, 147f  
in Krebs cycle, 126f  
oxazolidinones, **565t**, **572**, 585  
vancomycin resistance and, 572  
oxidase enzymes, 114, 115t  
oxidase test, 137  
oxidation ponds, in sewage  
treatment, **794**  
oxidation reaction, **120**, 120f, 121f  
in hot-air sterilization, 188, 191t  
oxidation-reduction reaction (redox  
reaction), 115t, **120**, 120f  
in Krebs cycle, 125–126, 126f  
oxidative burst, 462  
NADPH and, 463b  
toxic oxygen products of, 462  
oxidative phosphorylation,  
**120–121**, 127f  
aerobic respiration and, 135t  
anaerobic respiration and, 135t  
ATP yield and, 130t, 135t  
oxidizing agents, 199, 202t  
oxidoreductase enzyme, 114, 115t  
oxygen (O<sub>2</sub>)  
atomic number/atomic weight, 27t  
bacterial growth and, 158–160, 159t  
crosses plasma membrane by simple  
diffusion, 91  
electronic configuration, 28t  
as final electron acceptor, 135t, 141f  
as inorganic compound, 33  
microbial growth and, 158–160, 159t  
in organic compounds, 36  
photosynthetic cyanobacteria and,  
320–322  
photosynthetic planktonic algae  
and, 348  
photosynthetic processes and, 138,  
139f, 143, 143t, 344  
planktonic algae and, 348  
as poisonous gas, 158, 159–160  
reducing media to grow anaerobes,  
163, 164f  
singlet, 60, **159**  
spontaneous generation theory and,  
7, 8, 9f  
toxic forms of, 158, 159–160, 462  
oxygenic photosynthetic bacteria, **141**,  
141f, 143t, **320–322**, 321f, 321t  
OxyPlate petri plates, 163  
oxytetracycline (Terramycin), 565t, 570  
ozone, **160**  
as disinfectant, 199, 202t  
in water treatment plants, 788, 788f,  
789f  
ozone layer in atmosphere, UV light  
and, 227  
ozone layer of atmosphere, UV light  
and, 227
- P**  
P antigen, 385  
p53 gene, 258  
PAA/peroxyacetic acid (peracetic acid),  
199, 202t  
PABA (*para*-aminobenzoic acid),  
**563–564**  
sulfonamides and, 118, 563–564  
TMP-SMZ mode of action and,  
573, 573f  
packaging materials, bioplastic, 3b. *See*  
*also* aseptic packaging  
*Paecilomyces fumosoroseus*, 341  
*Paenibacillus*, exhibiting bacterial pack  
behavior, 56b, 56f  
*Paenibacillus polymyxa*, Polymyxin  
derived from, 560t  
pain  
of inflammation, 463  
prostaglandins role in, 465  
paints, copper, mercury added to  
prevent mildew, 195  
palivizumab (Synagis), 692  
palmitic acid, 39f  
PAMPs. *See* pathogen-associated  
molecular patterns  
pandemic disease, 18, **409**  
Paneth cells, 713  
defensins released by, 579, 713  
pantothenic acid, 115t  
paper products, microbes in  
manufacture of, 244  
*Papillomavirus*, 377t. *See also* human  
papillomavirus (HPV)  
Papovaviridae, 377t, **387**, 388t, 445t

- cauliflower mosaic virus caused by, 396*t*  
 as DNA virus, 387  
 multiplication of, 387*f*, 388*t*  
 as an oncogenic virus, 393  
 papovavirus, 387, 387*f*, 388*t*  
 cytopathic effects of, 445*t*  
 papules (lesions), 591, 592*f*  
 para-aminobenzoic acid (PABA), 563–564  
 sulfonamides and, 118, 563–564  
 Parabasalids, 356*t*  
 parabens, 202*t*  
 paragonimiasis, 364*t*  
*Paragonimus kellicotti*, 357–358, 359*f*  
*Paragonimus* spp., 364*t*  
 parainfluenza disease, 378*t*  
 paralysis  
   flaccid, caused by botulinum toxin, 439, 616  
   polio and, 627, 632*b*  
 paralytic rabies (in animals), 623  
 paralytic shellfish poisoning (PSP), 346, 356*t*, 446  
*Paramecium*, 60*f*, 61*f*, 62*f*, 63*f*, 65*t*, 66*t*, 348–349, 349*f*, 353*f*  
*Paramecium multimicronucleatum*, 62*f*  
 Paramyxoviridae, 378*t*  
*Paramyxovirus*, 378*t*, 391  
 parasites, 5–6, 143  
   animal, 5–6  
     of bacteria (*Bdellovibrio*), 301*t*  
     biological transmission of disease and, 414, 414*t*  
   blood, 330, 350, 667*f*, 668*b*  
   coevolution between host and, 429  
   human, 348–353  
   intestinal, 330, 349, 350*f*, 356–362, 356*f*, 358*f*–361*f*, 364*t*  
   intracellular, 300*t*, 302*t*, 303  
   major groups of, 6  
   natural killer (NK) cells can attack, 495  
   pathogenic mechanisms of, 446  
   plant, oomycetes as, 347  
   protozoa, 5, 349. *See also* parasitic protozoa  
   vectors and, 363, 364*t*  
   viruses as, 281, 370, 370*t*  
   worms (helminths), 6  
 parasitic bacteria  
   *Brucella*, 305  
   *Rickettsias*, 304  
 parasitic helminths, 6, 14, 14*f*, 189, 330, 331*f*, 355–363, 364*t*  
   antibody-dependent cell-mediated cytotoxicity and, 491, 492*f*  
   flatworms, 6, 353, 356–358, 356*f*–361*f*, 364*t*  
   flukes, 356–357, 358*f*, 364*t*  
   identification by microscope, 281  
   roundworms, 6, 330, 360–362, 362*f*, 364*t*, 446  
 parasitic infections  
   IgE increases during, 481  
   of skin, 607–609, 608*f*  
   as top 20 causes of death, 330  
 parasitic protozoa  
   antibody-dependent cell-mediated cytotoxicity and, 491, 492*f*  
   encystment and survival outside host, 349  
   features/diseases caused by/source of infection, 356*t*  
     *Giardia lamblia*, 349, 350*f*  
     *Plasmodium vivax*, 351–352, 352*f*, 446  
     *Trichomonas vaginalis*, 349, 350*f*  
   parasitic water molds, 345*t*, 347–348  
   parasitic worm infections, eosinophils increase during, 456  
 parasitic worms  
   IgE antibodies and, 485  
   immune system attacks on, 491, 492*f*  
 parasitism, 405. *See also* parasites  
 parasitology, 14  
 parenchyma, in tissue repair, 465  
 parent cells, parental DNA strands, 210–215, 211*f*–213*f*  
 parenteral route of entry/exit, 392*b*, 430, 431*t*, 447, 447*f*  
 parrots, as disease reservoirs, 413*t*  
 parthenogenesis, 308*b*  
 Parvoviridae, 377*t*, 387, 388*t*  
 parvovirus B19, P antigen and, 385  
 parvoviruses, DNA and, 48*t*  
 passive immunity  
   acquired, 498, 498*f*  
   gamma globulin most often used to transfer, 498  
   natural (at birth), 498, 498*f*  
 passive transport processes, 91–93, 91*f*  
   facilitated diffusion, 91–92, 91*f*  
   osmosis, 91*f*, 92–93, 92*f*  
   simple diffusion, 91, 91*f*  
 Pasteur, Louis, 8, 9, 9*f*, 10*f*, 11, 181, 187, 479, 507  
*Pasteurella* genus/spp., 301*t*, 312  
*Pasteurella multocida*, 282*b*, 312, 507  
 Pasteurellales, 301*t*, 312  
 pasteurization, 8, 187–188, 191*t*  
 patch test to determine cause of dermatitis, 535  
 pathogen-associated molecular patterns (PAMPs), 452, 460, 461*f*  
 pathogenic amebae, 350–351, 351*f*  
 pathogenic bacteria (human), 300*t*, 301*t*, 302*t*. *See also* specific bacterium  
   plasmids coding for proteins that enhance, 235  
   refrigerator temperatures and, 156, 156*f*, 189  
 pathogenic bacteria (plants), 300*t*, 301*t*. *See also* specific bacterium  
 pathogenic fungi, 339–341, 340*t*  
   summary of, 340*t*  
 pathogenic microbes/microorganisms, 2  
   modern chemotherapy and, 12, 12*f*  
   vegetative, disinfection to control, 182, 183*t*  
   virulence determination, 70  
 pathogenic prokaryotes, included in Domain Bacteria, 274  
 pathogenicity mechanisms, 402, 429–450, 447*f*  
   of algae, 446  
   altered, 228. *See also* mutations  
   Clinical Case, 430*b*, 436*b*, 442*b*, 444*b*, 446*b*  
   damaging host cells, 436–443, 447*f*  
   by producing toxins, 436–443, 437*f*, 438*f*, 440*f*, 441*t*, 442*t*  
   entering the host, 430–433, 431*t*  
   of fungi, 445  
   of helminths, 446  
   lysogeny and, 441–442  
   number of invading microbes and, 432, 447*f*  
   penetrating host defenses, 433–435, 435*f*  
   plasmids and, 441–442  
   portals of entry, 430–431, 431*t*  
   portals of exit, 446  
   prophages and, 441  
   of protozoa, 445–446  
   virulence and, 429, 432, 447*f*  
   of viruses, 443–444, 444*f*, 447*t*  
 pathogens, 401  
   bacterial biosensors to detect, 786*b*  
   first line of defense against, 452*f*, 453–456, 474*t*. *See also* immunity  
   second line of host defenses, 452*f*, 456–474, 474*t*. *See also* immunity  
   that can cause multiple diseases, 406  
   third line of defense against, 452*f*  
 pathology (science of), 402  
   objectives/areas of study, 402  
 paucibacillary leprosy, 619  
 PCR. *See* polymerase chain reaction  
 peanut butter, aflatoxin and, 445  
 peanuts  
   aflatoxin and, 227, 445  
   food allergies and, 531  
 peas, food allergies and, 525  
 pectin, 266, 267*t*  
   in cell walls of diatoms, 345*t*, 346  
 pediculosis (lice), 363, 364*t*, 597*b*, 608–609, 609*f*  
   head, ivermectin effective against, 572  
   Lyme disease and, 325  
   *Pediculus* and, 363*f*, 364*t*, 597*b*, 608  
   sucking, 364*t*  
   treatments for, 608–609  
   typhus transmitted by, 304  
*Pediculus humanus capitis* (head louse), 608, 608*f*  
*Pediculus humanus corporis* (human louse), 364*t*, 608  
   transmits typhus, relapsing fever, 363*f*, 364*t*, 413*t*  
*Pediococcus*, summer sausage and, 134*t*  
*Pelagibacter* genus/spp., 292, 303, 327  
*Pelagibacter ubique*, 303, 327, 778  
   FISH studies and, 292, 303  
 pellicles  
   of euglenoids, 349, 350*f*  
   of protozoa, 99, 349  
 pelvic inflammatory disease (PID), 758, 758*f*, 767*b*  
   *Chlamydia trachomatis* causing, 758  
   ectopic pregnancies and, 752  
   *Neisseria gonorrhoeae* causing, 758  
   possible infertility resulting from, 752  
 pemphigus neonatorum (impetigo of newborn), 593  
 penetration stage in viral multiplication, 382*f*, 383, 385, 385*t*, 387*f*  
 penicillin, 12, 12*f*, 561*f*, 567–568, 567*f*  
   as a hapten, 481, 524  
   allergic reactions to, 481, 530, 537*b*  
   desensitization and, 530  
   blood-brain barrier and, 616  
   cephalosporin structure compared to, 569*f*  
   discovery of, 12, 12*f*, 558  
   gram-negative bacteria and, 86, 87*t*, 88  
   gram-positive bacteria and, 69, 87*t*, 88, 559  
   mode of action, 84, 85*f*, 88, 561–562, 561*f*, 567  
   natural, 567, 567*f*  
   penicillinase-resistant, 567, 568, 568*f*  
   peptidoglycan and, 87*t*, 88, 100, 556  
   produced by *Penicillium* mold, rDNA techniques and, 247  
   resistance to, 18, 316, 568, 568*f*  
   retention of, 567, 568*f*  
   as secondary metabolite of industrial fermentation, 809, 810*f*  
   semisynthetic, 567–568, 567*f*  
   spectrum of activity and, 567–568  
 penicillin G, 564*t*, 567–568, 567*f*, 568*t*  
 penicillin V, 564*t*, 567, 567*f*  
 penicillinase-resistant penicillins, 567, 568, 568*f*  
 penicillinases ( $\beta$ -lactamases), 567, 568, 568*f*  
*Penicillium chrysogenum*, antibiotic penicillin derived from, 4*t*, 12, 12*f*, 560, 560*t*  
*Penicillium* genus/spp., 338, 341  
   semisynthetic penicillin and, 568  
   used to ripen cheeses, 799  
*Penicillium griseofulvum*, antibiotic griseofulvin derived from, 560*t*  
*Penicillium notatum*, 12, 12*f*, 559  
 penis, 751, 751*f*  
 pentamidine, to treat African sleeping sickness, 633  
 pentamidine isethionate, to treat *Pneumocystis pneumonia*, 575  
 pentose phosphate pathway (hexose monophosphate shunt), 123, 125, 127, 133  
   NADPH and, 466*b*  
   in purine/pyrimidine biosynthesis, 145–146, 146*f*  
 pentoses, 37  
 PEP (phosphoenolpyruvic acid), 93  
 PEP (postexposure prophylaxis), rabies and, 629  
 peptic ulcer disease, *Helicobacter pylori* and, 64*b*, 313, 314*f*, 725–726, 725*f*  
 peptidases, 134–135  
 peptide antibiotics. *See* antimicrobial peptides  
 peptide bonds, 43, 44*f*, 45*f*, 217, 217*f*  
 peptide cross-bridge, 84, 85*f*, 88  
 peptides, 43, 86  
 peptidoglycan (murein), 4, 38, 84, 85*f*, 89*f*  
   archaea cell walls and, 274, 326  
   in bacteria cell walls, 81*f*, 84, 85*f*, 86, 87, 87*t*, 88, 333*t*, 439  
   gram-negative, 85*f*, 86, 87*t*  
   gram-positive, 69, 84, 85*f*, 87*t*, 452  
   biosynthesis of, 144, 144*f*

- in eukaryotes vs. prokaryotes, 76, 100, 100*t*
- fungi and, 333*t*
- lysozyme damage to, 87*t*, 88, 455
- in prokaryotic cell walls, 76, 100*t*
- peptone iron agar, to detect hydrogen sulfide production, 137, 137*f*
- peptones, complex culture media and, 163
- peracetic acid (peroxyacetic acid/PAA), 199, 202*t*
- perforin, **458, 493**
- perfringolysin O toxin AFM micrograph, 64*f*, 67*t*
- pericarditis, **647, 649b**
- pericentriolar material, 98*f*, 104
- Peridinium*, 344*f*
- periodontal disease, **715–716**, 716*b*
- period of convalescence in infectious disease, **410**, 413*f*
- period of decline in infectious disease, **410**, 410*f*
- period of illness in infectious disease, **410**, 410*f*
- periodontitis, **715–716**
- peripheral nervous system (PNS), **616**, 616*f*
- leprosy pathogen and, 619–620, 620*f*
- rabies virus and, 622
- peripheral proteins, of plasma membrane, 89–90, 89*f*
- periplasm, 86
- periplasmic space, 87*t*
- peristalsis, **455**, 474*t*
- in response to microbial toxins, 455
- peritoneal macrophages, 460
- peritoneal tuberculosis, 142*b*
- peritonitis, 322, 407, 418
- peritrichous flagella, 80*f*, **81**
- permeability
- of blood vessels in inflammatory response, 464, 464*f*
- selective, **90**
- permease, 221, 221*f*
- permeases (transporter proteins), in facilitated diffusion, 91–92, 91*f*
- peroxidase, 3*b*, **160**
- peroxide
- as bleaching agent, chlorine vs., 3*b*
- yeasts in production of, 3*b*
- peroxide anion, **160**
- peroxisomes, 98*f*, **104**
- peroxyacetic acid/PAA (peracetic acid), 199, 202*t*
- peroxygens, **199**, 202*t*
- persistent (chronic) viral infections, **394**, 394*f*, 396*t*
- person-to-person transmission
- of avian influenza versus, 18
- of Ebola hemorrhagic fever, 19
- perspiration, **455**, 590, 590*f*
- pertussis (whooping cough), 307, **687–688**, 688*f*, **706b**
- as emerging infectious disease, 419*t*
- incubation period, 431*t*
- as notifiable infectious disease, 424*t*
- portal of entry, 431*t*
- portal of exit, 446
- spread by droplet transmission, 411–412, 412*f*
- treatment, 688
- vaccine, 14, 506*t*, 507*t*, 508, 687
- pest control
- Bacillus thuringiensis*, used in, 16, 315–316, 315*f*
- fungi used for, 341
- microorganisms used in, 16
- pest resistance, modified into crop plants, 246*f*, 263–264
- Pestivirus*, 377*t*
- Petri dishes, 162
- Petri, Julius, 10*f*
- Petri plates/culture plates, 162
- Petroff-Hausser cell counter, 173, 175*f*
- petroleum products
- bacteria that can use as energy source, 235
- beta-oxidation of, 134
- formed from diatoms/planktonic organisms, 348
- Peyer's patches, 459, 459*f*, 716
- M cells and, **489**, 490*f*, 716
- Pfiesteria*, 347, 356*t*
- PFU (plaque-forming units), 376*f*, **379**
- PG (polygalacturonase), 266
- pGH (porcine growth hormone), 267*t*
- pH buffers, **35**
- pH scale, **35**, 35*f*
- pH values, 34–35, 35*f*
- disinfectant activity and, 191
- enzymatic activity and, **117**, 117*f*
- extreme, acidophilic archaea and, 326
- microbial growth and, 37, 156
- pH scale, 35*f*
- PHA (polyhydroxyalkanoate), as biodegradable alternative to plastic, 3*b*
- Phaeophyta (algae), brown algae characteristics, 345*t*
- phage conversion, **384**
- phage DNA, 235, 247, 381–385, 382*f*, 383*f*, 384*f*
- phage libraries, 253, **253f**
- phage lysozyme, **381**, 383
- phage therapy, 371, 585
- phage typing, **287**, 289*f*, 712
- phages, **371**. *See also* bacteriophages
- phagocytes, 451*f*, **460–463**, 461*f*
- aging and progressive inefficiency of, 465
- defective or nonfunctioning, 466*b*
- fixed macrophages, **460**
- inability to produce and, 465
- macrophages as, **456**, 457*t*, 460, 460*f*, 490
- microbes that survive inside, 462
- migration and, 464*t*, 465
- as second line of defense, 452*f*, 460, 474*t*
- phagocytic vesicle (phagosome), 461*f*, **462**
- phagocytosis, 93, 100, 457*t*, **460–463**, 461*f*
- adaptive immunity's role in, 460, 487, 489–490, 490*f*, 500*f*
- Bacillus anthracis* capsule and, 43*b*, 44*b*
- biofilms and, 462
- Brucella* able to survive, 305
- capsule presence and, 80
- capsules of pathogens impairs, 433
- cells that perform, 457*t*, 460, 460*f*, 461*f*, 474*t*
- complement system proteins enhance, 467
- IgG antibody and, 483*t*
- in inflammatory response, 461*f*, 462
- mechanism of, 460–463, 461*f*
- migration and, 464*f*, 465
- Streptococcus pneumoniae* and, 232, 433
- Streptococcus pyogenes* and, 317
- toxic forms of oxygen and, 160, 461*f*
- phagolysosomes, 461*f*, **462**
- phagosome (phagocytic vesicle), 461*f*, **462**
- phalloidin, **445**
- pharmaceutical agents, algae-produced thickeners used in, 343
- pharmaceutical products, genetically modified, 257–258, 259*t*
- pharmaceutical uses for fermentation end-products, 134*t*
- pharyngeal gonorrhea, **756**
- pharyngitis, streptococcal (strep throat), 317, **682**, **683**, 683*f*, **686b**
- phase-contrast microscopy, **57**, 60*f*, 65*t*
- phenol (carbolic acid), **192**, 193*f*, 201*t*
- early uses in surgery, 11, 192
- enrichment mediums and, 166
- phenolics, **192**, 193*f*, 201*t*
- endospores, mycobacteria and, 201*t*
- phenotype, **208–209**
- changes in, 226. *See also* mutations
- identifying mutants, 228–229, 229*f*, 230*f*
- reversions and, 230–231, 230*f*
- phenylalanine (phe), 42*t*
- pHisoHex, 192
- Phlebotomus* (sand fly), leishmaniasis and, 356*t*, 665
- phocid distemper virus, found in seals, 282*b*
- phosphatase test, pasteurization and, 187
- phosphate
- in DNA structure, 47, 48*f*
- in RNA structure, 49*f*
- phosphate functional group, 36, 36*t*
- in DNA replication, 211*f*–214*f*
- in nucleotides, 208
- in phosphoproteins, 44
- phosphate salts
- buffering effect of, 156
- culture media and, 156
- phosphoenolpyruvic acid (PEP), 93
- phosphoglyceric acid, 140*f*, 146*f*
- phospholipids, **40**, 40*f*, 89, 89*f*
- phosphoproteins, 44
- phosphorus cycle, **780**
- phosphorus (P)
- atomic number/atomic weight, 27*t*
- electronic configuration, 28*t*
- microbial growth requirements, 158
- in organic compounds, 36
- sources of, 158
- phosphorylation, **120**
- type used to generate ATP, compared, 135*t*
- photic (light) zone of bodies of water, 344*f*, 345
- algal habitats and, 344–345, 344*f*
- photoautotrophic prokaryotes, included in Domain Bacteria, 274
- photoautotrophs, **141–143**, 141*f*
- carbon requirements, 158
- culture media for, 167*t*
- photoheterotrophs, 141, 141*f*, **143**
- photolyase (light-repair enzyme), 211*t*, 227, 228*f*
- photophosphorylation, **121**, **138**, 139*f*
- cyclic, **138**, 139*f*
- noncyclic, **138**, 139*f*
- photosynthesis, 2, 105*f*, 121, **138**, 139*f*
- algae and, 5, 138, 141, 141*f*, 143*t*, 343–347, 344*f*, 345*t*
- anoxygenic, **142**, 143*t*, 321–322, 321*t*
- bacterial, 4. *See also* photosynthetic bacteria
- bacterial plasma membrane enzymes and, 90
- carbon dioxide, carbohydrates and, 15
- chloroplasts and, 105, 105*f*, 138
- cyanobacteria and, 138, 141, 141*f*, 143*t*
- Euglena* and, 5
- in eukaryotic vs. prokaryotic microbes, 143*t*
- lichens and, 342
- life without sunlight, endoliths and, 779–780
- light-dependent (light) reaction stage, **138**, 139*f*
- light-independent (dark) reaction stage, **138**, 139*f*
- oxygenic, **141**, 143*t*, 320–322
- in prokaryotic vs. eukaryotic microbes, 143*t*
- photosynthetic algae, 343–347, 344*f*, 345*t*
- photosynthetic bacteria, 4, 141–143, 141*f*, 143*t*, 300*t*, 301*t*
- anoxygenic, 95, 141*f*, **142**, 143*t*, 302*t*, 321*t*, 323–326, 325*f*
- cyanobacteria, 138, 302*t*, 320–322, 321*f*, 321*t*
- enzyme required by, 95
- oxygenic, 302*t*, 320–322, 321*t*
- summary of selected characteristics, **321t**
- photosynthetic pigments, 138, 141*f*, 143*t*
- of algae, 344–347, 345*t*
- as energy source, 141*f*
- photosynthetic protozoa, 5, 349–350*f*, 350*f*
- photosystems I and II, **138**, 139*f*
- phototaxis, **82**
- phototrophs, **140**, 141*f*
- phycobiliproteins, 344*f*, 345*t*
- phylogenetic relationships, 273–277
- hierarchies, 275, 277, 277*f*
- of prokaryotes, 280, 280*f*
- rRNA sequencing/ribotyping to trace, 292
- of the three Domains, 273–275, 274*f*, 276*t*
- phylogeny (systematics), **273**
- phylum (taxonomic), defined, **278**, 279*f*
- phosphorus cycle, **774**
- Physarum*, 355*f*
- physical methods of microbial control, 185–188, 191*t*
- Phytophthora*, California oak trees “sudden oak death”, 348



- Phytophthora cinnamoni*, *Eucalyptu*  
trees infected by, 348
- Phytophthora infestans*, potato/  
soybean/cocoa crops infected  
by, 347–348
- Phytophthora ramorum*, oak, redwood  
trees infected by, 348
- phytoplankton, **783**
- pia mater, 616, 617f
- pica cravings, 741
- pickles  
lactic acid fermentation and, 135t, 806
- pH and, 156
- Picornaviridae, 377t, **388**, 388t,  
389f, 390b
- picometer, **54t**
- PID. *See* pelvic inflammatory disease
- pig influenza viruses, 18
- pigeons, cryptococcosis and, 632
- pigments  
bacterial, protection from sunlight  
and, 190
- photosynthetic, 138, 141f, 143t  
of algae, 343, 345t
- pigs  
bird flu and, 374–377b  
as disease reservoirs, 413t  
genetically modified, artificial blood  
and, 258  
genetically modifying as organ  
donors, 536  
heart valves of, 535  
influenza A virus subtypes and, 18,  
374–375b  
tapeworm in, 359, 364t
- pili/pilus, 79f, **83–84**  
conjugation (sex) pili, **84**, 234, 236f
- pilin, 83
- pilot whales, CM virus and, 282b
- pimaricin (Natamycin), 197
- pin, of T-even bacteriophage, 376f, 382f
- pink eye/red eye (conjunctivitis),  
**609–610**, **609b**
- pinocytosis, 93, 100
- pinworm (*Enterobius vermicularis*),  
361, 362f, 364t, 740b, **741**
- Pityrosporum*, as normal microbiota of  
skin, 404t
- placebo, in experimental  
epidemiology, 422
- placental transfer of immunoglobulins,  
483t, 494
- plague, 364t, 447, **655**, **656b**,  
657–658, 657f  
as a biological weapon, 654b  
bacterial capsules, virulence and, 433  
bubonic, **656b**, **657**, 657f  
causative agent/arthropod vector, 413t  
disease reservoirs for, 413t  
distribution of, in U.S., 657f  
as notifiable infectious disease, 424t  
pneumonic, **658**  
portals of entry, 430  
rat flea (*Xenopsylla*) as vector, 364t,  
413t, 414t, 648  
septicemic, **656b**, **657**  
transmission due to, 413t  
vaccine, 650, 652  
*Yersinia pestis* causing, 311, 413t,  
433, 648  
as zoonotic disease, 413t
- Planctomyces* genus/spp., 302t, **322**, 324f  
*Gemmata obscuriglobus* and origin  
of eukaryotic nucleus, 322, 324f
- Planctomycetales, 302t
- Planctomycetes, 302t, **322**, 324f
- plankton (dinoflagellates), **345t**,  
346–347, 346f  
blooms and polluted water, 348  
photosynthesis of and Earth's  
oxygen supply, 348  
planktonic bacteria, biofilms and,  
161, 161f
- plant alkaloids, genetically modified,  
257
- plant breeding, 263–264, 266, 267t
- plant cells  
genetic modified to produce  
valuable products, 257  
Ti plasmids and, 264, 264f
- plant diseases, viroids causing,  
**396–397**
- plant pollens, allergic reactions and,  
528, 528t, 530, 530f
- plant rot, *Erwinia* causing, 311–312
- Plantae Kingdom, **281**  
energy source, 281  
in Linnaeus' classification system, 273  
organisms included in, 281  
position in evolutionary tree, 274f
- plants  
applications of rDNA technology,  
263–264, 264f, 266, 267t  
bacterial pathogens, 300t, 301t,  
303–305, 311–312  
cell structure (eukaryotic), 6, 75,  
97–106, 98f  
cultured, for rDNA purposes, 257  
genetically modified, 263–265, 264f,  
266, 267t  
advantages of, 257  
as "factories" for producing  
desirable chemicals, 245  
introducing foreign DNA into,  
251–252, 252f, 263, 264f  
Ti plasmid and, 264, 265f  
uses of bacteria in, 257,  
263–264, 264f
- green  
as photoautotrophs, 141–142, 141f  
photosynthesis and, 138  
as kingdom in Domain Eukarya, 6,  
274, 274f, 281  
oxygen-producing and  
cyanobacteria, 320–322  
parasites, oomycetes as, 347  
photosynthesis and, 143t  
as potential source for vaccines, 506  
*Spiroplasma* and, 318  
viruses of, 395–396, 396t
- plaque (tooth/dental), biofilms and, 161
- plaques (prion), 395
- plaques (viral), **376**, 376f, 379  
plaque-forming units (PFU), **379**
- plasma, blood, **201**, **456**, 472b
- plasma cells, 484f, **485**, 494, 500f
- plasma membrane (cytoplasmic  
membrane), **89**, **100**  
antifungals that damage, 564t  
antimicrobials that damage, 90, 186,  
194, 196, 201t, 202t, 561f, 562t,  
563, 564f, 566–567
- electron transport chain (system)  
and, 129  
of eukaryotic cells, 98f, 100–101, 100t  
functions of, 90, 100  
injury by antimicrobial drugs, 561f,  
565t, 572  
membrane ruffling and, 435, 435f  
movement of materials across,  
91–93, 91f, 92f, 100, 134  
penetration by invasins, 435  
phospholipids of, 40, 40f, 89, 89f  
of prokaryotic cells, 40, 40f, 79f, 85f,  
**89–91**, 89f, 100, 100t  
proteins of, 89–90, 89f  
selective permeability of, 90, 186  
sterols and, 41, 41f, 87, 89, 558  
structure of, 89–90, 89f  
of T-even bacteriophage, 381, 382f  
viruses lacking, 370t
- plasma sterilization, **198–199**
- plasma viral load (PVL), **551**
- plasmid library, 253f
- plasmids, 79f, **94**, 207, 207f  
*Agrobacterium tumefaciens* and, 263,  
264f, 305  
antibiotic resistance and,  
235–237, 238f  
bacteriocins and, 235  
in cell's genome, 208  
circular DNA as protective, 249  
in cloning and, 248–249, 249f  
conjugative, **235**, 236f  
dissimilation, **235**  
F factor and, 94, 234, 236f  
genetic modification techniques  
and, 237, 248–249, 249f, 258  
pathogenicity and, 441–442  
R factors and, 235–237, 238f, 249,  
249f, 441–442  
recombinant, 246f, 258  
Ti plasmids and, **263**, 264f  
in typical genetic modification  
procedure, 245, 246f  
as vectors, 248–249, 249f, 258, 305  
acting as shuttle vectors, 249  
for cloning, 248–249, 249f, 255,  
255f, 305  
Ti plasmids for plant genetic  
modification, 263–264, 264f  
virulence factors and, 441–442  
yeasts and expression of foreign  
eukaryotic genes, 257
- plasmodial slime molds, **353–354**, 355f
- Plasmodium falciparum*, 663
- Plasmodium* genus/spp., 330,  
**351–352**, 352f  
*Anopheles* mosquito and, 365, 414t  
can survive in phagocytes, 462  
pathogenic mechanism of, 446  
vector requirements of, 365
- Plasmodium malariae*, 663
- Plasmodium ovale*, 663
- plasmodium (slime mold),  
**353–354**, 355f
- Plasmodium vivax*, 351–352, 352f,  
356t, 669, 670. *See also* malaria
- Anopheles* mosquito as vector,  
351–352, 352f, 362–363, 364t,  
413t, 663
- incubation period, 431t
- pathogenic mechanisms of, 446
- portals of entry, 431t  
reservoirs for, 413t
- plasmogamy, **335**, 338f
- plasmolysis, 93, **156**, 157f, 191t
- plastic  
biodegradable alternative to, **3b**  
made by microbes, **3b**
- plate counts, **171**, 172f, 173f
- platelets, **457t**  
histamine present in, 464, 464f  
thrombocidin produced by, 473
- platensimycin, 566
- platinum, used in staining of  
specimens, 61
- Platyhelminthes, 355, **356**, 364t. *See*  
*also* flatworms
- pleated sheets protein structure, 44, 45f
- pleomorphic bacteria, **78**  
actinobacteria and, 318–320
- pleura, 676f, 681
- pleurisy, 693
- pleuromutilins, 565t, 572
- Pleurotis mutilus* (mushroom), 572
- pluripotent stem cells, 535
- PMNs/polymorphs  
(polymorphonuclear  
leukocytes), 456
- pneumatocyst of algae, 344, 344f
- pneumococcal meningitis, **614**, 623b
- pneumococcal pneumonia vaccine, 14
- Pneumocystis*, 284, 340–341  
as emerging eukaryotic pathogen, 330  
as leading cause of death in AIDS  
patients, 330, 341
- Pneumocystis carinii*. *See* *Pneumocystis*  
*jirovecii*
- Pneumocystis jirovecii*, 419t, 550t  
identification difficulties, 284  
life cycle of, 705f  
as an opportunistic pathogen, 405
- pneumonia, 20, 272f, **703–704**,  
705f, **706b**
- Pneumocystis pneumonia*  
in AIDS patients, 20, 330, 340–341,  
405, 419t, 549, 550t, **703–704**,  
705f, **706b**  
identification difficulties, 284  
pentamidine isethionate to treat, 569  
trimethoprim-sulfamethoxazole to  
treat, 697
- pneumonia, **687**  
antibiotic resistant, as an emerging  
infectious disease, 419t  
atypical vs. typical, 692, 693  
bacterial, **685–692**, **687b**  
bronchopneumonia, 685  
chlamydial, 322, **687b**, **689**  
compromised hosts and, 416  
etiology determination and, 407  
fluoroquinolones to treat, 567  
fungal (*Aspergillus*), 452b  
*Haemophilus influenzae*, 312, 433,  
613, **693**, **695b**  
incubation period, 431t  
*Klebsiella pneumoniae* causing, 5f,  
282b, 310, 416t, 433  
legionellosis (Legionnaires' disease),  
**694**, **695b**  
lobar, 685  
methicillin-resistant *Staphylococcus*  
*aureus* and, 419t

- mycoplasma, 318, 318f, 565, **693–694**, 694f, **695b**  
 nosocomial, 416t, 417t  
*Pasteurella* causing, 312  
*Pneumocystis jirovecii* causing, 272f, 284, 405, 419t, 550t, 697, 698f  
 pneumococcal. *See*  
   pneumococcal pneumonia  
 portal of entry, 430, 431t  
 portal of exit, 446  
 psittacosis (ornithosis), **694–696**, **695b**  
 Q fever and, 695b, 696–697, 696f  
 spread by droplet transmission, 411–412, 412f  
*Staphylococcus aureus* causing, 416t  
 streptococcal bronchopneumonia post-influenza, 409  
*Streptococcus pneumoniae* causing. *See* pneumococcal pneumonia  
 typical vs. atypical, 692, 693  
 vaccine, 14, 693  
 vancomycin-resistant *Staphylococcus aureus* and, 419t  
 viral, **692**  
   walking, 694  
 pneumonic plague, **648**  
 pneumococcal meningitis, **619**, 623b  
 pneumococcal pneumonia, 14, 317, 431t, 433, 506t, 507–508, 507t, **693**, 693f, **695t**  
 PNS (peripheral nervous system), **616**, 616f  
 point mutation (base substitution), **224–225**, 224f  
 poison ivy reactions, 535, 536f  
 poisonous gases, oxygen as, 158, 159–160  
 poisons, enzyme, 118  
 polar flagella, 80f, **81**  
 polar head of phospholipids, 40, 40f, 89, 89f  
 polar molecule, **33**  
   water as, 33–34  
 polio. *See* poliomyelitis  
 poliomyelitis (polio), **626–628**, 626f, 627f, 632b  
   diagnosis of, 626  
   epidemiology/eradication efforts, 628  
   incidence, worldwide, 627, 627f  
   iron lung developed for, 626, 626f  
   as notifiable infectious disease, 424t  
   poliovirus causing, 626. *See also* poliovirus  
   portals of entry, 430, 632b  
   portals of exit, 446  
   postpolio syndrome, 627  
   vaccine, 14, 506t, 507t, 627–628, 632b  
 poliovirus, 377t, 406, 626–627  
   cytopathic effects of, 445t  
   GI tract as portal of entry, 430, 632b  
   as an icosahedral virus, 373  
   as potential biological weapon, 654b  
   size of, 372f  
   uncoating in, 386  
   vaccine, 14, 506t, 507, 627–628, 632b  
 pollens, plant  
   allergic reactions and, 528, 528t, 530, 530f  
   as antigens, IgE antibodies and, 481, 528, 529f  
   localized anaphylaxis and, 529, 530, 530f  
 pollution  
   bacterial biosensors to detect, **786b**  
   bioremediation and, 16, 32b  
   oil-spill/oil-eating bacteria to degrade, 32b  
   water, 16, 32b, **778–779**  
 poly-beta-hydroxybutyric acid, 95  
 polyene antibiotics, 566t, **568**, 568f, 574, 574f  
 polyester manufacture, bacteria used in, 3b  
 polyethylene glycol, 251, 252f  
 polygalacturonase (PG), 266  
 polyhedral (icosahedral) virus, 372f  
 polyhedral viruses, 372f, **373**  
 polyhydroxyalkanoates (PHA), 3b  
 polymerase chain reaction (PCR), **249–251**, 250f  
   deep-sea hydrothermal vents and, 157b  
   as diagnostic tool, 251, 522  
   DNA chips and, 261, 292, 292f, 522  
   DNA probes and, 261, 521–522  
   to identify microorganisms  
     from ancient *Bacillus* bacteria, 290  
     causing human granulocytic ehrlichiosis, 290  
     H1N1 influenza virus, 290  
     Hantavirus hemorrhagic fever outbreak, 290  
     in norovirus outbreak, 265b  
     rabies virus source, 290  
     West Nile virus, 380  
     of Whipple's disease, 290  
   to match donors in transplant surgery, 539  
   microarrays and, 261, 292, 292f, 517  
   MRSA strains differentiated by, 423b  
   nucleic acid amplification tests and, 290–291  
   real-time PCR, 251, 290  
   reverse-transcription PCR, 251, 251b, 265b  
   soil samples and, 326  
   to study extinct plants/animals, 264  
   Taq polymerase enzyme and, 326, 767  
   to track HIV infection transmission, 258b  
 polymers, **37**  
 polymorphonuclear leukocytes (PMNs/polymorphs), 456  
 polymorphs/PMNs (polymorphonuclear leukocytes), 456  
 polymyxin B, 561f, 565t, **572**  
   plasma membrane damaged by, 90, 561f, 565t, 572  
   to treat imipenem-resistant gram-negative infections, 95b  
*Polyomavirus*, 377t  
   cytopathic effects of, 445t  
 polypeptide antibiotics, 564t, **569**  
 polypeptide chains, in DNA translation, 216–217f, 217  
 polypeptides, **43**  
   in bacterial cell walls, **84**, 85f  
 polyribosomes, 101, 218f  
 polysaccharides, **38**  
   as antigens, 481  
   biosynthesis of, 144, 144f  
   in capsules, phagocytosis evasion and, 80, 232  
   core, 85f, **86**  
   granules, **95**  
   O, 85f, **86**  
 Pompe disease, 259t  
 pond algae  
   scum formed by filamentous green algae, 346  
   *Volvox*, 5f  
 Pontiac fever, **694**  
 "popcorn" strain of *Wolbachia*, 308b  
 populations (bacterial)  
   defined, 153  
   logarithmic representations, 169–171, 169f  
 porcine growth hormone (pGH), 267t  
 pores of integral proteins, 89f, 90  
 porins, 85f, **86**, 200, 309, 555  
 pork tapeworm, 359, 364t, 413t  
*Porphyromonas*, periodontitis and, 716  
 portals of entry, **430–431**, 431t, **447f**  
 portals of exit, **446–447**, **447f**  
 Porter, Rodney R., 10f  
 posaconazole (Noxafil), 574  
 positive (direct) selection to detect mutant cells, **229**  
 positive regulation of *lac* operon, 221–222, 223f  
 positive RNA, 220b  
 positive staining, electron microscopes and, 62  
 postexposure prophylaxis (PEP), rabies and, 629, 631b  
 postherpetic neuralgia, 602  
 postoperative infections, principal sites of, 417t  
 postpolio syndrome, 627  
 potassium clavulanate (clavulanic acid), 568  
 potassium hydroxide (KOH), to diagnose cutaneous mycoses, 601  
 potassium (K)  
   atomic number/atomic weight, 27t  
   microbial requirements, 158  
 potassium sorbate, 197  
 potato crops  
   genetically modified to produce antigenic proteins, 509  
   insect toxin genetically modified into, 266  
   Ireland's great potato blight, 347–348  
   *Phytophthora infestans* infecting, 347–348  
   potato spindle tuber viroid (PSTV), 396, 397f  
 potato spindle tuber viroid (PSTV), 396, 397f  
 potential chemical energy, Krebs cycle and, 125–127, 126f  
 potential energy, 120, 139  
 Potyviridae, watermelon wilt caused by, 396t  
 poultry  
   cephalosporin-resistance in *E. coli* transferred to *Salmonella enterica* in, 583b  
   as disease reservoirs, 413t  
   fowl cholera in caused by *Pasteurella*, 312  
   influenza A virus subtypes and, 18, 374b  
   *Salmonella* bacteria in intestinal tract of, 310  
 pour plate method of plate counts, **171**, 173f  
 povidone-iodine, 194  
 Poxviridae, **377t**, 385, **386**, 388t  
   as DNA virus, 386  
   as an oncogenic virus, 393  
 poxviruses, 374, 376f, 386  
 prairie dogs  
   monkeypox and, 601  
   plague endemic to, 657  
 praziquantel, 562t, 566t, **577**  
 prebiotics, 456  
 precipitation curve, 514f  
 precipitation reactions, **514–515**, 514f, 515f  
 precipitin ring test, **515**, 515f  
 precursors in amino acid synthesis, 145  
 predatory bacteria (on other bacteria), 312–313  
 predisposing factors, disease and, **410**  
 prednisone, 446b  
 pregnancy  
   chlamydial infections and, 750  
   cytomegalovirus and, 760  
   fetus as foreign tissue, rejection and, 539  
   gonorrhea infection and, 748–749  
   group B *Streptococcus* (GBS) screening and, 324b  
   home tests, 520, 522f  
   immune system tolerance of fetus and, 534–535  
   *Listeria monocytogenes* and, 317, 620  
   neonatal herpes and, 757–758  
   normal microbiota of reproductive tract and, 751  
   pelvic inflammatory disease and, 752  
   rubella and, 424t, 599, 760  
   syphilis and, 760, 761  
   *Toxoplasma gondii* dangers to, 352  
 premergent flagellum, of euglenoids, 351, 351f  
 preparation of specimens, 64, 67–71.  
   *See also* stains/staining  
 pressure cookers, 185, 187  
 prevalence of disease, **406**  
*Prevotella* genus/spp., 302t, 322  
*Prevotella intermedia*, trench mouth and, 716, 716b  
 primary amebic meningoencephalitis, **623b**, **634–635**, 635f  
   Clinical Case, 616b, 621b, 635b, 637b, 639b, 662b  
 primary cell lines, **379**  
 primary immune response, 490b, 494b, **497**, 497f  
   vaccines provoke, 505  
 primary infection, **409**  
 primary sewage treatment, **789**, 790f  
 primary stain, **68**, 71  
 primary structure of proteins, 43, 45f  
 primase (RNA), 211t, 212f  
 Primaxin, 569

- primers  
nucleic acid, 251, 251f  
in PCR microarrays, 261  
PCR process and, 250f  
RNA, 211t, 212f
- prions, 19, 395, 395f, 636–637, 636f, 637t, 638b  
emerging infectious diseases caused by, 19, 419t  
how proteins become infectious, 395, 395f  
irradiation of foodstuffs does not inactivate, 797t  
mad cow disease and, 19, 200, 395, 419t, 636f, 637, 637t  
resistance to chemical biocides, 200, 200f  
resistance to sterilization methods, 183f, 630  
sheep scrapie and, 636  
size of, 372f  
spongiform encephalopathies caused by, 395, 636–637, 636f, 637t, 638b
- privileged sites/tissues, transplant rejection and, 539–540
- probes, DNA, 255, 256f  
to identify pathogens, 255
- probiotics, 456  
lactic acid bacteria used as therapy, 456
- procaine penicillin, 567, 568f
- processes, cell membrane, of B cells, 478f
- Prochlorococcus*, 777
- prodromal period in infectious diseases, 410, 410f
- produce DNA viruses, 378t
- product, in chemical reactions, 32, 115, 116f, 119f
- profundal zone, 783
- proglottids, 358, 360f
- programmed cell death (apoptosis), 489, 489f
- progressive encephalitis, 396t
- prokaryotes/prokaryotic cells, 4, 75, 76–97, 79f, 299–328  
archaea included in, 4, 75, 76, 300.  
See also archaea  
bacteria included in, 4, 75, 76, 300.  
See also bacteria  
cell division in, 76, 100t  
cell wall composition in, 76, 100t  
classification of, 278–280, 279f, 280f  
diversity among, 327–328  
DNA arrangement in, 75, 76, 100t  
eukaryotes vs., 76, 81, 82, 100t, 101, 273, 274, 276t  
evolution and, 275, 275f  
evolutionary relationships and, 280, 280f  
flagella of, 81–82, 81f, 82f, 100t  
genetics of, 208–210, 210f  
DNA replication, 210–215  
protein synthesis, 215–218  
glycocalyx of, 100t  
historical and current definitions of, 273  
identifying difficulties, 281  
mutation and, 223–231  
identification techniques, 231
- organelles absent in, 76, 100t  
origins of, 273, 274f, 277, 277f  
pH ranges and, 35  
photosynthetic, 141–143, 143t, 321t  
phylogenetic relationships and, 280, 280f  
plasma membrane of, 89–90, 89f, 100t  
protein synthesis in, 215–218, 216–217f, 218f  
ribosomal differences, 95, 95f  
rules for naming and, 278  
shapes of, 77–78, 77f, 78f, 100t  
sizes of, 77, 100t, 327  
species of, vs. eukaryotic species, 278, 280  
structures of, 78–97, 79f, 79f  
external to cell wall, 78–84  
internal to cell wall, 89–97  
taxonomic classification of, 278–280, 280f
- proline (pro), structural formula/characteristic R group, 42t
- promoter, 214f, 215, 220, 221f, 222f, 223f  
inducible, 255
- proofreading abilities of DNA polymerase, 214–215
- properdin (factor P) complement protein, 467, 468f, 470f
- prophage, 383f, 384, 384f  
lysogenic conversion and, 442  
vs. provirus, 390
- Propionibacterium acnes*  
bacterial acne caused by, 319, 599–600  
as normal microbiota of skin, 591, 594  
pH ranges and, 35
- Propionibacterium freudenreichii*, Swiss cheese and, 134t, 319
- Propionibacterium* genus/spp., 132f, 302t, 319  
added to cheese in ripening process, 805  
fermentation and, 132f, 137  
lactic acid use of, 137  
as normal microbiota of eye, 404t  
as normal microbiota of skin, 404t
- propionic acid  
bacteria that produce, 302t  
as fermentation end-product, 132f, 134t, 137
- Propionibacterium* genera able to produce, 319
- prospective studies, 424
- prostaglandins, 440, 440f, 464, 464f, 529  
in allergic reactions, 529  
aspirin, acetaminophen inhibit synthesis of, 440  
fever and, 440, 440f, 466
- prostate cancer vaccine, 543
- prostheses, 303  
of *Caulobacter*, 304  
of *Hyphomicrobium*, 304
- protease enzymes, to inactivate prions, 200
- protease inhibitors, 548, 571, 576
- proteases, 134–135  
granzymes, 458, 489
- protein denaturation  
by antimicrobial agents, 184, 194, 201t, 202t  
by pasteurization, 187–188, 191t
- protein kinase, 471
- protein synthesis, 215–218, 216–217f  
early discoveries about, 15  
evolutionary aspects, 105  
genetic code and, 208, 219f  
Golgi complex and, 102–103  
inhibitors  
antimicrobial agents, 194  
antimicrobial drugs, 561f, 562–563, 563f, 565t, 570–572  
nitrogen requirements for, 158  
prokaryotic cells, 215–218, 216–217f, 218f  
site of, 94, 101, 215  
transcription and, 210f, 214f, 215, 218  
vs. eukaryotic cell, 105, 218  
regulation of, 218–223  
ribosomes and, 101, 215–218, 216–217f  
RNA and, 146, 208, 216–218, 216–217f  
transcription and, 215, 218, 218f  
translation and, 215–218, 216–217f, 218f
- proteinaceous infectious particle (prion), 395, 395f
- proteins, 41–44  
amino acids found in, 41, 42t  
as antigens, 481  
antimicrobial agents and, 184  
antiviral (AVPs), 47f, 471–473  
biosynthesis of, 144–145, 145f  
catabolism of, 134–135, 136f  
complement, 466–470. See also complement system  
in complex culture media, 162–163, 163t  
conjugated, 44  
denaturation of, 44, 117, 117f  
by heat treatments, 185–188, 191t  
DNA as blueprint for, 209, 210f  
enzymatic activity of. See enzymes  
enzymatic vs. structural, 209  
flagellin, 81  
functions of, 41  
globular, flagellin, 81  
Human Proteome Project and, 260  
Human Proteome Project to map, 260  
infectious (prions), 395, 395f  
iron-binding, 473  
negative staining in study of, 62  
phenotypes and, 209  
proteomics science and, 261  
simple, 44  
structural vs. enzymatic, 209  
structure of, 43–44, 45f  
synthesis of. See protein synthesis  
three-dimensional shape of, 43, 44, 45f, 184  
transporter, 41
- proteobacteria, 279f, 300–301t, 303–313, 321t  
important genera/special features, 300–301t  
photosynthetic bacteria of, 321t  
phylogenetic relationships, 274f, 279f, 280f, 303
- proteomics, 261  
Human Proteome Project and, 260
- Proteus* genus/spp., 301t, 311, 311f  
as endotoxin producer, 441  
L forms of, 88  
as normal intestinal bacteria, 404t  
as normal urethral bacteria, 404t  
swarming growth of, 81, 82f, 311, 311f
- Proteus mirabilis*, 311, 311f  
rapid identification methods, 285f
- Protista (kingdom), 6, 273, 280
- protists, 6, 273, 274f, 280  
clades and, 280  
fossils and, 277  
Kingdom Protista and, 273, 280
- proton acceptors, bases as, 34
- proton donors, acids as, 34
- proton motive force, 128
- proton pumps, 128–129, 128f, 129f
- protons, 26, 26f  
in cellular oxidations, 120, 121f  
in chemiosmosis, 128–129, 128f
- protoplast fusion, 251–252, 252f
- protoplasts, 88, 251, 252f  
protoplast fusion, 251, 252f
- protozoa/protozoan, 2, 4–5, 5f, 7, 7f, 330, 331f, 348–353  
as aerobic heterotrophs, 349  
AIDS-related diseases caused by, 550t  
antimicrobial drugs that inhibit, 12, 528, 529f, 562t  
cell structure, 5, 5f, 98f, 99, 349  
characteristics of, 348–349  
as chemoheterotrophs, 141f, 143  
classification and, 349  
conjugation in, 348–349, 349f  
cysts, 349  
antimicrobial agents and, 203, 203f  
emerging infectious diseases caused by, 419t  
as eukaryotes, 6, 76, 98f, 99, 348  
habitat of, 348  
identification by microscope, 181  
immune system attacks on, 491, 492f  
as insecticides, 348  
life cycle of, 348–349  
locomotion and, 5, 5f  
medically important phyla, 349–353  
nutritional requirements, 6, 141, 141f, 349  
parasitic, 349–350, 356t  
Pasteur's research on, 11  
pathogenicity of, 445–446  
photosynthetic, 5, 349–350, 350f  
reproduction in, 5, 348–349  
resistance to chemical biocides, 200, 200f  
rules for naming and, 278  
silkworm disease and, 11
- protozoan diseases, 356t, 445–446  
of cardiovascular system, 666–673  
of digestive system, 736–738, 740b  
of eyes, 605, 609b  
of lymphatic system, 650b, 656b, 660–666  
of nervous system, 623b, 633–635, 635f, 638b



- of reproductive system, 759b, 760–761, 761b  
zoonotic, 413t
- prourokinase, genetically modified, used in anticoagulant therapy, 259t
- provirus, 390–391, 391f  
HIV as, 547, 547f
- PrP<sup>C</sup> (cellular prion protein), 395, 395f
- Prusiner, Stanley B., 10f, 395
- Prydiction* genus/spp., 302t
- pseudohypha, 333, 335f, 340t
- pseudomonad infections, 596, 598–599. *See also Pseudomonas aeruginosa*
- Pseudomonadales, 301t, 307–309, 307f
- Pseudomonas aeruginosa*, 308, 558, 558f, 589f
- biofilm-forming, 56b, 56f, 462
- carbenicillin effective against, 568, 569
- Clinical Case
- corneal transplant, 559b, 570b, 579b, 581b, 584b, 585b
  - swimming pool, 590b, 599b, 605b, 607b, 611b
- disinfectants and, 193, 193f
- doripenem effective against, 569
- nosocomial infections and, 415, 416t
- R factors and genes determining antibiotic resistance, 415
- skin infections caused by, 596, 597b, 598–599
- as superbug, 580
- triclosan resistance and, 193, 193f
- twitching motility in, 83
- Pseudomonas carboxydohydrogena*, 143
- Pseudomonas dermatitis*, 596, 597b, 598–599
- Pseudomonas fluorescens*
- bloodstream infection (Clinical Case), 154b, 166b, 175b, 177b
  - genetically modified to produce *Bacillus* toxin, 266, 267t
  - indwelling catheters and, 309
- Pseudomonas* genus/spp., 301t, 307–309, 307f
- ability to degrade/detoxify compounds and, 235
  - anaerobic respiration and, 130
  - antibiotic resistance and, 309
  - antibiotics effective against, 565
  - biochemical tests and, 137
  - bioremediation uses, 16, 32b
  - classification changes and, 278, 308
  - cystic fibrosis patients and, 309
  - dermatitis caused by, 596, 597t, 598–599
  - disinfectants and active growth in, 196–197
  - dissimilation plasmids and, 235
  - Entner-Doudoroff pathway and, 125
  - grow at refrigerator temperatures, 309
  - grow in quats, 196–197, 309
  - hospital-acquired infections and, 309, 598–599
  - nitrogen in fertilizers/soil lost due to, 309
  - as normal microbiota of urethra, 404t
  - as oil degraders, 32b
  - quat compounds and, 196–197, 201t, 202t, 309
  - resistance to chemical biocides, 196, 196f, 200, 309
  - soil as common habitat, 307
  - urinary tract infections and, 752
  - Zephiran resistance and, 196, 201b
- Pseudomonas putida*, 3b
- Pseudomonas syringae*, 267t, 308
- pseudomurein, 87
- pseudopods, 4, 5f, 350, 351f, 461f, 462
- of amoebae, 4, 5f, 350, 351f
  - of *Amoeba proteus*, 351f
- psittacosis (ornithosis), 322, 413t, 694–696, 695b
- Clinical Case, 681b, 696b, 697b, 699b, 701b, 705b
  - as notifiable infectious disease, 424t
  - reservoirs/transmission methods, 413t
- psoriasis, 538
- interleukin-12 therapy to treat, 499b
- psoriatic arthritis, 538
- PSP (paralytic shellfish poisoning), 346, 356t, 446
- PSTV (potato spindle tuber viroid), 396, 397f
- psychotrophs, 154, 154f, 158
- growth at refrigerator temperatures, 191–192
- psychrophiles, 154, 154f
- psychrotrophs, 154f, 155
- public health
- antibiotic-resistant bacteria, 18
  - E. coli* O157:H7 outbreaks, 19
  - emerging infectious diseases and, 17–20, 418
  - public health issues
    - measles vaccination, 510b
    - West Nile virus, 220b, 631, 634b
- pUC19 plasmid vector, 249f
- puerperal fever. *See* puerperal sepsis
- puerperal sepsis (childbirth fever), 11, 197, 420, 647, 649b
- pulmonary (inhalational) anthrax, 432, 652, 654b, 655b
- pulmonary syndrome, *Hantavirus*, 378t, 413t, 416, 419t
- pulmonary tuberculosis, 142b
- Pulmozyme (rhDNase), genetically modified, 259t
- pulsed-field gel electrophoresis (PFGE), 724
- PulseNet, to track foodborne diseases, 261
- puncture wounds, fungal infections and, 340, 340t
- pure bacterial cultures, streak plate method for obtaining, 167, 167f
- Purell hand sanitizer, 195, 735
- purine nucleotides, 47
- biosynthesis of, 115t, 145–146, 146f
- purple bacteria, 141, 141f, 142, 143t
- purple nonsulfur bacteria, 141, 141f, 143, 302t, 321t, 324
- gammaproteobacteria and, 324
- purple photosynthetic bacteria, 302t
- purple sulfur bacteria, 143, 302t, 315f, 321t, 324, 325f
- alphaproteobacteria and, 324
- pus, 465
- phenolics to disinfect, 192
- pustules (lesions), 587f, 591
- inflammatory response and, 465
- putrefaction spoilage, of canned foods, 795, 796t
- PVL (plasma viral load), 551
- pyantel pamoate, 566t
- pyelonephritis, 752, 753b
- pyocyanin, 598
- pyrimidine dimers, 211t
- pyrimidine nucleotides, 47
- biosynthesis of, 115t, 145–146, 146f
- Pyrococcus*, 157b
- Pyrococcus furiosus*, 157b
- Pyrodictium abyssi* (archaea), 326f
- Pyrodictium* (archaea), 302t
- pyrogenic response (fever), 452f, 466.
- See also* fever
- endotoxins causing, 440, 440f
- pyrogenic toxin, 442
- pyruvic acid
- alcohol fermentation and, 133f
  - coenzymes and, 115t
  - fermentation and, 123f, 130, 131, 132, 132f, 133f
  - glycolysis and, 123f, 124, 124f, 125
  - Krebs cycle and, 125, 126f
  - lactic acid fermentation and, 133f
  - in lipid biosynthesis, 145f
  - in lipid catabolism, 136f
  - in nucleotide biosynthesis, 146f
  - in polysaccharide synthesis, 144f
- Q**
- Q fever, 95, 309, 462, 695b, 696–697, 696f
- as notifiable infectious disease, 424t
- qPCR (quantitative PCR), 251
- quadruple reassortant virus, 374–377b
- quantitative PCR (qPCR), 251
- quaternary ammonium compounds.
- See* quats
- quaternary structure of proteins, 44, 45f
- quats (quaternary ammonium compounds), 90, 193f, 196–197, 202t
- chemical structure of, 196, 196f
  - effectiveness against endospores, mycobacteria, 201t
  - enveloped viruses and, 196, 199b, 202t
  - Pseudomonas*, *Burkholderia* actively grow in, 200
- quinacrine, 577
- quinine, 12, 577
- to control malaria, 12, 577
  - inducing cytotoxic reaction, 528, 529f
- quinolones, 561f, 565t, 572, 585, 721
- quinones, 115t
- quinupristin, 565t, 571
- quorum sensing, biofilms and, 56b, 160–161
- R**
- r-determinant gene of R factors, 236, 238f
- R factors (resistance factors), 235–237, 238f
- antibiotic resistance and, 235–237, 238f, 309, 415, 441–442, 580, 583b
  - plasmids as vectors and, 249, 249f
  - resistance transfer factor (RTF) genes and, 236, 238f
  - transposons and, 237, 238f, 580
- R groups of organic compounds, 36t, 37
- R groups (side groups) of amino acids, 41, 41f, 42t
- R100 (resistance plasmid R100), 236, 238f
- rabbit fever/deer fly fever. *See* tularemia
- rabbies
- culturing viruses in, 379
  - as disease reservoirs, 656b
  - raccoon roundworm and, 360, 364t
  - tularemia and, 648, 656b
- rabies, 628–630, 628f, 630f, 631b, 632b
- bat bites and, 631b, 631f
  - diagnosis of, 62, 629, 631b
  - disease reservoirs for, 413t
  - distribution in wildlife, 629–630, 630f
  - furios (classical) 629 type, 629
  - hydrophobia and, 629
  - immunofluorescence to diagnose, 59
  - incidence, by animal species, 630, 630f
  - incubation period, 431t, 628–629
  - as notifiable infectious disease (animal/human), 424t
  - paralytic (dumb or numb) type, 629
  - portals of entry, 431t, 628, 628f
  - portals of exit, 446
  - postexposure prophylaxis for, 629
  - prevention of, 629
  - signs in animals, 629
  - symptoms in humans, 629
  - transmission due to, 413t
  - treatment for, 629, 631b
  - vaccines, 380, 629
  - as zoonotic disease, 413t, 622, 625b
- rabies virus, 378t, 390, 390f. *See also* rabies
- as a *lyssavirus* member, 390, 630
  - as a rhabdovirus, 390
  - can mimic neurotransmitter acetylcholine, 443
  - disease reservoirs, 413t
  - bats as 628, 630, 630footnote
  - silver-haired bat rabies variant, 631b, 631f
  - encephalitis cases and, 629
  - as helical virus, 373
  - inclusion bodies produced by, 443, 444f
  - incubation period, 431t, 628–629
  - PCR used to identify source, 290
  - portals of entry, 431t
  - size of, 372f
  - transmission due to, 413t
  - vaccine for animals, 507
  - vaccine for humans, 506t
- raccoons
- as disease reservoirs, 330, 413t, 419t
  - reported cases of rabies in, 630f
  - roundworm *Baylisascaris procyonis*, 360, 364t
- radiant energy spectrum, 189–190, 190f
- radiation
- Deinococcus radiodurans* resistant to, 326
  - of foods (to preserve), 803–804, 803f, 803t, 804f

- gamma, provirus expression and, 391  
 ionizing, **189–190**, 190*f*, 191*t*, 227  
 to kill microbes in foods, 189,  
 796–797, 797*t*, 798*f*  
 mutagenic, 227–228  
 nonionizing, **190**, 190*f*, 191*t*  
 sterilizing, 189–190, 190*f*, 191*t*  
 radiation therapy, impaired innate  
 defenses and, 465  
 radicals  
   hydroxyl, **162**  
   superoxide, **159–160**  
 radioactive cesium-137, lichen and, 342  
 raltegravir, 553, 576  
 Ramaskrishnan, Venkatraman, 13*t*  
 random mutations, 429  
 Rapamune (sirolimus), 542  
 rapid diagnostic tests (RDTs) for  
   syphilis, **761**  
 rapid identification methods,  
   **285–286**, 285*f*  
   using DNA probes, 290, 291*f*, 292  
 rapid immunohistochemical test  
   (RIT), **629**  
 rapid plasma reagin (RPR) test, for  
   syphilis, **761**  
 rapidly growing mycobacteria, 201*b*  
 rashes, **591**, 592*f*  
   antibiotic-induced, 531*b*  
   Clinical Case, 590*b*, 599*b*, 605*b*,  
   607*b*, 611*b*  
   delayed, 531*b*  
   diseases that cause, 594*b*, 596*b*, 597*b*  
   enanthem, **591**  
   exanthem, **591**  
 rat liver extract, 230–231, 230*f*  
 rats  
   plague and, 311  
   rat bite fever, **654–655**, **655*b***  
   rat flea (*Xenopsylla*) transmitting  
   plague, typhus, 304, 311, 363*f*,  
   364*t*, 413*t*, 648  
   *Yersinia pestis* bacteria carried by,  
   311, 413*t*  
 RBCs. *See* red blood cells  
 rDNA. *See* recombinant DNA (rDNA)  
   technology  
 RDTs (rapid diagnostic tests), for  
   syphilis, **755**  
 reaction rate, **113**  
 reading frames, translational,  
   frameshift mutations and, 225  
 reagents in Gram staining, 86  
 real-time PCR, 251  
 RecA protein, 64*f*, 67*t*  
   in *E. coli*, 64*f*, 67*t*  
   in genetic transformation, 231*f*, 233  
 receptor-mediated endocytosis,  
   100–101  
   as viral entry method, **385**, 385*t*, 386*f*  
 receptor sites, in viral multiplication, 385  
 receptors for pathogens, 431*f*, **432**  
 recipient cells in gene transfers, 231*f*,  
   **232**, 234*f*  
 recognition sites, in transposition, 237  
 recombinant DNA (rDNA)  
   technology, 14–15, 16,  
   244–271, **245**, 246*f*  
   advantages, 245, 257–258, 506  
   applications, 16, 257–266  
   agricultural, 263–264, 266, 267*t*  
   scientific, 260–263  
   therapeutic, 16, 257–258, 259*t*  
   biotechnology and, **16**, 244–271,  
   **245**. *See also* biotechnology  
   enzymes produced by, 16, 247–248,  
   248*f*, 248*t*  
   ethical issues, 267  
   gene therapy and, 16  
   genetic modification techniques,  
   251–257  
   genetic recombination and,  
   231–239. *See also* genetic  
   recombination  
   Human Genome Project and, 260  
   Human Proteome Project and, 260  
   overview, 245–247, 246*f*  
   safety issues, 266  
   vaccines produced by, 16, 245,  
   508, 509  
 recombinant interferons (rIFNs), 472  
 recombinant plasmids, 246*f*, 258  
 recombinant vaccines, **508**, 509  
 recombinants/recombinant cells,  
   210*f*, 232  
 reconstructive surgery, genetically  
   modified morphogenic  
   proteins, 259*t*  
 recreational water-associated  
   diarrhea, 357*b*  
 rectangular-shaped bacteria, 79, 79*f*  
 red algae, 344*f*, **345*t***, **346**  
 red blood cells (RBCs), 457*t*. *See also*  
   erythrocytes  
   ABO blood type and, 532–533, 532*t*  
   compound light microscope  
   micrograph, 58*f*  
   size of, 372*f*  
 red bone marrow, 458, 459*f*  
   lymphocyte maturation and, 480,  
   541*b*  
   radiation therapy damage to, 465  
 red eye/pink eye (conjunctivitis),  
   **609–610**, **609*b***  
 red tides, **346–347**, 446, 785, 785*f*  
   algal blooms and, 348  
   paralytic shellfish poisoning and,  
   446  
 Redi, Francesco, 7  
 redness, of inflammation, 466  
 redox reaction (oxidation-reduction  
   reaction), 115*t*, **120**, 120*f*  
   in Krebs cycle, 125–127, 126*f*  
   reducing culture media, **163**, 164*f*, 167*t*  
 reduction, **120**, 120*f*. *See also* redox  
   (oxidation-reduction) reaction  
 redwood trees, *Phytophthora ramorum*  
   and, 348  
 Reed, Walter, 659  
 refractive index, 57, 59*f*  
 refrigeration  
   to control microbial growth, 155,  
   155*f*, 156*f*, 188–189, 191*t*  
   to preserve cultures, 167–168  
   temperature and microbial growth  
   in, 155, 155*f*, 156*f*, 188–189, 309  
 refrigerators  
   *Clostridium botulinum* and, 618  
   *Listeria monocytogenes* and, 317, 620  
   pathogenic bacteria and  
   temperatures of, 156, 156*f*,  
   188–189  
   *Pseudomonas* and, 309  
   psychotrophs growing in, 188–189  
 regulatory genes, I gene, 221, 221*f*  
 regulatory proteins  
   CD59 of complement system, 470  
   repressors, **219**, 222*f*  
 regulatory T cells, **489**  
 rehydration therapy, oral, 717  
 reindeer, lichens and, 342  
 reinforcement (relative brightness),  
   in phase-contrast microscopy,  
   57, 60*f*  
 relapsing fever, 325, 364*t*, **656*b***, **658**  
   *Borrelia* and, 325, 658  
   causative agent/arthropod vector,  
   414*t*  
   *Ornithodoros* (tick) as vector, 364*t*,  
   414*t*  
 relative brightness (reinforcement),  
   in phase-contrast microscopy,  
   57, 60*f*  
 relative darkness (interference), in  
   phase-contrast microscopy,  
   57, 60*f*  
 relaxation pathway, tetanospasmin  
   and, 439  
 relaxin, genetically modified, 259*t*  
 release stage in viral multiplication,  
   382*f*, **383**, 385*t*, 387*f*, 389*f*,  
   **391–392**  
 Relenza (zanamivir), 566*t*, 575, 701  
 Remicade (infliximab), 512  
 rennin  
   in cheese making, 805  
   genetically modified, 267*t*  
 Reoviridae, **378*t***  
 Reoviridae, 378*t*  
 Reoviridae, 388*f*, 388*t*, **390**  
 Reoviridae, wound tumor virus (in  
   plants), 396  
 reoviruses, RNA strands and, 48*t*  
 repellants (chemotactic signals), 82  
 replica plating to identify mutation,  
   **229–230**, 229*f*  
 replication, semiconservative, **212**  
 replication enzymes (DNA), 210–215,  
   211*f*–214*f*, 211*t*  
 replication fork (DNA), 210, 211*f*  
   in *E. coli* bacteria, 213, 213*f*  
   events at (summary), 212*f*  
 replication of DNA. *See* DNA  
   replication  
 repressible genes, 219–221, 222*f*  
 repressible operons, **221**, 222*f*  
 repression, **219–221**, 221*f*, 222*f*  
 repressor proteins, **219**, **221**, 221*f*,  
   222*f*  
 reproductive choices, genetic  
   screening, ethics involved,  
   261, 267  
 reproductive methods  
   of algae, 331*f*, 344, 345*f*, 345*t*  
   of archaea, 326  
   of bacteria, 4, 168, 168*f*, 304, 308*b*,  
   315, 333*t*  
   of fungi, 4, 331*f*, 334–335, 335*f*–339*f*  
   of helminths, 355, 356  
   parthenogenesis, 308*b*  
   of protozoa, 5  
   sporulation. *See* sporulation  
   of viruses, 5  
 reproductive systems, **749**, 750, 751*t*  
   bacterial diseases of, 754–763,  
   766*b*, 767*b*  
   fungal diseases of, 765–766,  
   766*b*, 767*b*  
   normal microbiota of, 404*t*  
   protozoan diseases of, 766, 767*b*  
   structure/function of, 750, 751*f*  
   viral diseases of, 763–765, 767*b*  
 reptiles, as disease reservoirs, 413*t*  
 research, medical, importance of  
   rDNA technology to,  
   257–258, 259*t*  
 reservoirs of disease, **411**, 413*t*  
   animal and human, 411, 413*t*, 414*t*  
   bats as especially good, 628,  
   630*footnote*  
   nonliving (soil and water), 409  
   of zoonoses/with transmission  
   methods, 413*t*  
 residual body formation in  
   phagocytosis, 461*f*, 462  
 resistance, **17**, **451**. *See also* immunity  
   to antibiotic drugs, 12, 237. *See also*  
   antibiotic resistance  
   to drought, modified into crop  
   plants, 264  
 resistance factors in bacteria. *See*  
   R factors  
 resistance plasmid R100, 236, 238*f*  
 resistance transfer factor (RTF),  
   **236–237**, 238*f*  
 resistant mutants, antibiotics and,  
   581, 582*f*  
 resolution (resolving power) of  
   microscopes, **56–57**, 58*f*  
 resolving power (resolution), of  
   microscopes, **56–57**, 58*f*  
 respiration  
   breathing and, 122  
   cellular, **125**. *See also* cellular  
   respiration  
 respirators, as disease reservoirs, 417  
 respiratory infections, *Serratia*  
   and, 311  
 respiratory syncytial virus (RSV),  
   **698–699**, **706*b***  
 respiratory system, **680–710**, 681*f*, 682*f*  
   bacterial diseases, 677–692,  
   **681*b***, **699*b***  
   diseases commonly contracted via,  
   430, 431*t*  
   lower respiratory tract  
   bacterial diseases, 687–697  
   fungal diseases, 702–705  
   structure/function of, **681**, 682*f*  
   viral diseases, 697–702  
   microbial diseases of, 18, 56*b*, 80,  
   680–710  
   bacterial, 683–685, 687–698  
   fungal, 695–698, **699*b***  
   nosocomial, 416*t*, 417*t*  
   Reoviridae and, 378*t*, 390  
   viral, 390, 679–680, **681*b***  
   normal microbiota of, 312, 404*t*, 682  
   nosocomial infections and, 416,  
   416*t*, 417, 417*t*  
   physical defenses against microbes,  
   452, 452*f*, 680, 681*f*, 682*f*  
   structure/function, 681, 681*f*, 682*f*  
   upper respiratory tract

- bacterial diseases of, 683–685, **686b**  
 IgA antibody protection and, 480–481  
 as portal of entry, 430, 431*t*, **447f**  
 as portal of exit, 446  
 structure/function of, **681**, 681*f*  
 viral diseases of, 312, 386, 390, 685–686, **686b**  
 respiratory tracts, lower/upper. *See* under respiratory system  
 restaurant eating utensils, calcium hypochlorite to disinfect, 194  
 restriction enzymes, **247–248**, 248*t*, 249*f*  
 blunt ends/sticky ends, **247**, 248*f*  
 used in rDNA technology, 248*t*  
 restriction fragment length polymorphisms (RFLPs), **261**, 289  
 to identify viruses, 380  
 reticular dysgenesis, 544*t*  
 reticulate bodies, *Chlamydomophila psittaci* and, **323f**  
 reticuloendothelial system  
 brucellosis persists in, 644  
 macrophages and, **460**  
 retorts, 185, **800**, 801*f*  
 retapamulin, 565*t*, 572  
 retrospective studies, 424  
 Retroviridae, **378t**, **390–391**, 391*f*  
 biosynthesis of, 388*t*  
 HIV as, 378*t*, 390, 545  
 multiplication in, 390, 391*f*  
 mutation rate high in, 547  
 oncogenic, 391, 393–394  
 provirus and, 390–391  
 reverse transcriptase and, 390, 391*f*  
 used as vectors in gene therapy, 249, 258  
 retroviruses, 390–391, 391*f*  
 high mutation rate of, 547  
 HIV-1, HIV-2 as, 378*t*, 390, 545  
 oncogenic, 391, 393–394  
 reverse genetics, **261**, 694  
 reverse transcriptase, **253**, 254*f*, 388, 388*t*, **390**, 391*f*  
 Hepadnaviridae and, 388  
 HIV and, 387, 390, 545, 546*f*, 547  
 retroviruses and, 390, 390*f*, 392*b*, 393  
 reverse-transcription PCR (RT-PCR), 251  
 to track HIV infection, 251*b*  
 used to confirm norovirus outbreak, 265*b*  
 reversible chemical reactions, **33**, 38*f*  
 reversion rate, spontaneous, 230*f*, 231  
 reversions/revertant bacteria, 230–231, 230*f*  
 Reye syndrome, **601**  
 RFLPs (restriction fragment length polymorphisms), 258*b*, **261**, 290  
 DNA fingerprinting and, 261, 263*f*  
 Rh blood group system, **532–533**, 533*f*  
 rH factor, 528*t*, **533**, 533*f*  
 Rhabdoviridae, **378t**, 388*t*, 389*f*, **390**, 390*f*  
 cytopathic effects of, 445*t*  
 potato yellow dwarf virus caused by, 394*t*  
 rhabdoviruses, 389*f*, **390**, 390*f*  
 cytopathic effects of, 445*t*  
 Rhabdoviridae, potato yellow dwarf virus and, 396*t*  
 rhDNase (Pulmozyme), genetically modified, 259*t*  
 rheumatic fever, 317, **648**, 648*f*, **649b**  
 HLA typing to determine susceptibility, 539*t*  
 rheumatoid arthritis (RA), 463, **537**  
 interleukin-12 to treat, 499*b*  
 monoclonal antibodies to treat, 512  
 testing for immune-complex diseases, 472*b*  
 tumor necrosis factor and, 492, 512  
 rheumatoid factors, 537  
 Rhinovirus, 372*f*, 377*t*, 685. *See also* common cold  
 size of, 372*f*  
 rhizines, **342**, 343*f*  
 rhizobia, 304–305  
 Rhizobiales, 300*t*  
*Rhizobium* genus/spp. (rhizobia), 300*t*, 304–305  
 Entner-Doudoroff pathway and, 125  
 as pleomorphic bacteria, 78  
 sold industrially, 806  
 as symbiotic nitrogen fixers, 300*t*  
*Rhizobium meliloti*, genetically modified, 266, 267*t*  
*Rhizopus* genus/spp., **335**, 336*f*, 340*t*, 341  
*Rhizopus stolonifer*, 335*f*, 337  
*Rhodococcus bronchialis*, DNA fingerprinting and, 289, 289*f*  
*Rhodococcus erythropolis*, 143  
 Rhodocyclales, important genera of, 301*t*  
 Rhodophyta (algae), 345*t*  
*Rhodopseudomonas*, 143  
 Rhodospirillales, 300*t*  
*Rhodospirillum* genus/spp., 300*t*, 321*t*  
*Rhodospirillum rubrum*, chromatophores of, 90, 90*f*  
 RhoGAM, 528  
 ribavirin, 566*t*, 575  
*Ribeiroia*, 358*f*  
 riboflavin (vitamin B<sub>2</sub>), 115*t*  
 in cellular respiration, 127  
 ribonucleic acid (RNA), 47, 47*f*  
 ribose, 46*f*, **47**  
 ribosomal RNA (rRNA), 47, 94, 101, 208  
 as basis for phylogenetic system in latest *Bergey's Manual*, 299  
 ribotyping and, 292. *See also* rRNA sequencing  
 sequencing techniques. *See* rRNA sequencing  
 in study of evolutionary relationships, 273, 292  
 ribosomes, **94**, 94*f*, 98*f*, **101**  
 antibiotics and, 94, 563, 565–567  
 chloroplasts and, 104  
 eukaryotic, 100*t*, **101**, 102*f*, 103*f*, 276*t*  
 mitochondrial, 103  
 phylogenetic relationships and, 273  
 prokaryotic, 79*f*, **94**, 94*f*, 100*t*, 276*t*, 557, 558*f*  
 in translation, 216–218, 216–217*f*  
 viruses and, 370*t*  
 ribotyping, **292**  
 ribozymes, **119**, 211*t*, 218  
 ribulose 1, 5-diphosphate carboxylase, 95  
 ribulose diphosphate, in Calvin-Benson cycle, 140*f*  
*Rickettsia* genus/spp., 300*t*, **304**, 304*f*  
 antimicrobial drugs that inhibit, 562*t*  
 can survive in phagocytes, 462  
 culture media and, 164, 304  
 diseases caused by, 304  
 as parasites, 304, 462, 565  
*Pelagibacter* (ocean bacterium) related to, 292  
 taxonomic changes in, 299, 304  
 tetracyclines effective against, 565  
 viruses compared to, 370, 370*t*  
*Rickettsia prowazekii*, 300*t*, 304, 654–655  
 considered hazardous to culture, 655  
 epidemic typhus and, 304, 413*t*, 654–655, 656*b*  
 as potential biological weapon, 654*b*  
*Rickettsia rickettsii*  
 incubation period, 431*t*  
 portals of entry, 431*t*  
 reservoirs/transmission method, 413*t*  
 Rocky Mountain spotted fever and, 304, 413*t*, 431*t*, 661–662, 661*f*  
*Rickettsia typhi*  
 endemic murine typhus and, 304, 413*t*  
 reservoirs/transmission method, 413*t*  
 Rickettsiales, 300*t*  
 Rid (lice remedy), 608  
 rifampicin. *See* rifampin  
 rifampin, 539*b*, 561*f*, 565*t*, **572**  
 multidrug-resistant TB and, 18  
 to treat leprosy, 572, 626, 632*b*  
 to treat tuberculosis, 572, 684  
 rifamycins, 561*f*, 565*t*, **572**  
 rIFNs (recombinant interferons), 472  
 RIG (human rabies immune globulin), 629  
 right lymphatic duct, 458, 459*f*  
 ring stage, **351**, 352*f*  
 ringworm, 413*t*, 447, **497b**, **605–606**, 606*f*  
 athlete's foot (tinea pedis), 413*t*, **600**, 600*f*  
 disease reservoirs for, 413*t*  
 jock itch (tinea cruris), **605**  
 nails (tinea unguium), **600–601**  
 of skin or scalp, 597*b*, 601*f*, **605**  
 griseofulvin to treat, 569, 605  
 RISC (RNA-induced silencing complex), **258**, 258*f*  
 RIT (rapid immunohistochemical test), **629**  
 rituximab (Rituxan), 512  
 rhizosphere, 771–772  
 RNA-dependent RNA polymerase, 389*f*, 390  
 RNA-induced silencing complex (RISC), **258**, 258*f*  
 RNA interference (RNAi), **258**, **579**  
 RNA polymerase, 211*t*  
 in eukaryotic transcription, 218, 219*f*  
 in prokaryotic transcription, 214*f*, 215  
 repressor proteins and, 221, 221*f*, 222*f*, 223*f*  
 RNA primase, 211*t*, 212*f*  
 RNA primers, 212*f*  
 RNA (ribonucleic acid), 47, 47*f*  
 antibiotics that inhibit, 563, 565–567  
 antimicrobial agents and, 184  
 DNA compared to, 48*t*  
 in gene expression regulation, 218–223  
 messenger, 15, **47**, 208, **215**, 216*f*  
 microRNAs and, 222–223, 223*f*  
 naked, viroids and, 396–397  
 nucleotides, 214*f*, 215  
 processing in eukaryotic cells, 218, 219*f*  
 in protein synthesis, 146, 208, 215–218, 216–217*f*, 218*f*, 222–223  
 ribosomal (rRNA), **47**. *See also* ribosomal RNA  
 ribozymes and, **119**  
 structure, 208  
 transcription and, 214*f*, **215**  
 transfer (tRNA), 47  
 of viruses, 5, 370, 371  
 RNA-RNA hybridization reactions, 290  
 RNA synthesis  
 antibiotics that inhibit, 567  
 nitrogen requirements, 158  
 from nucleoside triphosphates with ribose, 214  
 phosphorus requirements, 158  
 RNA tumor viruses, 378*t*  
 RNA viruses, 377–378*t*, 385*t*, 388–392, 388*t*, 389*f*, 392*b*  
 DNA viruses compared to, 388*t*  
 multiplication of, 385*t*, 388–392, 388*t*, 389*f*  
 oncogenic viruses, 393–394  
 reverse transcriptase viruses, 388*t*  
 RNAi (RNA interference), **258**, 259*t*, 260, **579**  
 Roaccutane, 600  
 Robbins, Frederick C., 13*t*  
 Roberts, Richard J., 13*t*  
 rock-eating microorganisms, 143  
 Rocky Mountain spotted fever, 364*t*, 413*t*, 462, **656b**, **661–662**, 661*f*  
*Dermacentor* spp. as tick vector, 414*t*, 655, 661–662, 661*f*  
 life cycle of, 656*f*  
 disease reservoirs for, 413*t*  
 distribution of, in U.S. (2008), 661*f*  
 incubation period, 431*t*  
 as notifiable infectious disease, 424*t*  
 portals of entry, 431*t*  
 rash caused by, 662, 662*f*  
*Rickettsia rickettsii* and, 304, 413*t*, 414*t*, 661, 661*f*  
 as tickborne typhus, 661  
 transmission due to, 413*t*  
 transovarian passage of bacteria and, 661, 661*f*



- rod-shaped bacteria, 77, 77f, 106b
- rodents
- as disease reservoirs, 413t, 656b, 673
  - ground squirrels
  - plague and, 648, 650
  - tularemia carried by, 648, 656b
- Hantavirus* pulmonary syndrome associated with, 378t
- as pets
- rat bite fever and, 647–648, 650b
  - tularemia and, 656b
- prairie dogs and plague, 648, 650
- rats. *See* rats
- sarcoma viruses in, 393
- toxoplasmosis-infected, cats and, 661
- root nodules, 772, 773f
- Roquefort cheeses, ripened by *Penicillium* molds, 799
- Rose, Irwin, 13t
- Roselovirus* (HHV-6), 377t
- roseola, 387, 600
- herpesviruses 6 and 7 causing, 600
  - rash caused by, 594b
- Ross, Ronald, 13t
- rot, plant, 311
- rotating biological contactor system, 791
- Rotavirus*, 378t, 734–735, 736b
- vaccine, 506, 507t, 511, 735
- rough ER, 98f, 102, 103f
- RoundUp herbicide, 264, 267t
- roundworms (nematodes), 6, 330, 360–362, 362f, 364t
- freezing temperatures and, 189
- Rous, F. Peyton, 10f, 392
- Rous sarcoma virus, 445f
- RPR (rapid plasma reagin) test for syphilis, 755
- rRNA sequencing, 292
- of Archaea/Bacteria/Eukarya, compared, 276t
  - Chlamydia* species and, 278, 299
  - in fossilized materials, 277, 290
  - to show evolutionary relationships, 273, 275, 275f, 277, 290
  - “signature” sequences within domains, phylums, 292
- RSV (respiratory syncytial virus), 698, 706b
- RT-PCR. *See* reverse transcription PCR
- RTF (resistance transfer factor), 236–237, 238f
- rubber, synthetic, 257
- rubber tires, 143, 346
- rubbing alcohol (isopropanol), 37
- as antiseptic/disinfectant, 195, 202t
- rubella (German measles), 594b, 604–605, 609f
- congenital rubella syndrome, 604–605
  - as notifiable infectious disease, 424t
- incubation period, 431t
- macular rash caused by, 594b
- as notifiable infectious disease, 424t
- portals of entry, 431t
- pregnancy and, 424t, 760
- Rubivirus* causing, 377t, 396t, 431t
- vaccine, 14, 506t, 507f, 599–600
- Rubella virus, 377t
- incubation period, 431t
  - persistent viral infections and, 396t
  - portals of entry, 431t
  - transmission route, 377t
  - vaccine, 14, 506t, 507t
- rubella virus. *See* *Rubivirus*
- rubeola. *See* measles
- Rubulavirus* (mumps virus)
- incubation period, 431t
  - as notifiable infectious disease, 424t
  - portals of entry, 431t
  - vaccine, 14, 506t, 507t
- rust, white, 347
- rusts, 340t
- rye bread, fermentation and, 134t
- S**
- Sabin polio vaccine, 627
- Sabouraud’s dextrose agar, 165
- sac fungi (*Ascomycota*), 279f, 337–338, 338f, 340t
- Talaromyces* life cycle, 338f
- Saccharomyces carlsbergensis*, 800
- Saccharomyces cerevisiae* (baker’s yeast), 4t, 793f, 806
- as budding yeast, 333, 334f
  - cervical cancer vaccine and, 259t
  - colony-stimulating factor and, 259t
  - fermentation and, 132f, 133, 134t
  - genetic engineering and, 256, 259t, 341
  - hepatitis B vaccine and, 256, 341
  - influenza vaccine and, 259t
  - interferons and, 259t
  - plasmids and, 235
  - strains developed over centuries, 800
  - in taxonomic hierarchy, 279f
  - used to make bread, beer, wine, 341, 800
- Saccharomyces ellipsoideus*, 800
- Saccharomyces* genus/spp.
- ethanol produced by for brewed beverages, 332
  - in taxonomic hierarchy, 229f
- Saccharomyces uvarum*, 800
- Saccharomycetaceae, in taxonomic hierarchy, 279f
- Saccharomycetales, in taxonomic hierarchy, 279f
- Saccharopolyspora erythraea*, erythromycin derived from, 560t
- safety issues, in biotechnology, 266
- safranin stain, 67, 69, 71, 71t
- in capsule staining, 70, 70f, 71t
  - in Gram staining, 68, 70, 86, 87t
- Saint Vitus’ dance (Sydenham’s chorea), 648
- sake, microbes used in production of, 806
- saliva, 454, 714
- as defense against pathogens, 455, 474t
  - IgA antibodies in, 480
  - lysozyme in, 88, 455
  - lysozymes of, 714
  - pH of, 133b, 135b, 455
  - phenolics to disinfect, 192
  - as portal of exit, 446
  - possible pathogens in, 446
  - salivary amylase enzyme of, 455
  - spirochete bacteria and, 325
  - substances in that inhibit microbial growth, 455
  - sucrose lowers pH of, 133b
- salivary amylase, of saliva, starch digestion and, 455
- salivary glands, 454
- Salk polio vaccine, 507, 627
- salmon, DNA vaccine approved for, 508
- Salmon, Daniel, 4t
- Salmonella bongori*, 287b, 311
- Salmonella choleraesuis*, 285f
- Salmonella enterica*, 4t, 310–311, 719
- antibiotic therapy, lactic acid bacteria and, 456
  - cephalosporin-resistance transferred by *E. coli*, 583b
  - incubation period, 431t
  - phage typing to identify strain of, 289f
  - portals of entry, 431t
  - reservoirs/transmission method, 413t
  - salmonellosis caused by, 431t, 719–720, 719f, 720f, 728b
  - serovars/serotypes of, 310
- Salmonella* genus/spp., 301t, 310–311
- Ames test and, 230–231, 230f, 232b
  - biochemical tests to identify, 137, 137f, 284, 284f, 285f, 310–311
  - Bt toxin and, 264
  - complement system evasion by, 470
  - directly damaging host cells, 436
  - DNA chips and, 261, 292, 292f
  - DNA probes and, 290, 291f, 292
  - E. coli* and, host’s plasma membrane and, 435, 435f
  - as enteric bacteria, 284, 284f, 310
  - fermentation and, 132f
  - flagellar proteins of, genetic transfers and, 231–232
  - Kauffmann-White scheme to differentiate, 310–311
  - nomenclature and, 310
  - resistance plasmid R100 and, 236–237
  - serovars (serotypes) and, 287b, 290b, 310, 515
  - tracking infection outbreaks, 273b, 286b, 287b, 290b, 293b, 294b
- Salmonella montevideo*, 721b
- Salmonella tennessee*, serotyping, DNA fingerprinting, 290b, 293b, 294b
- Salmonella typhi*, 311
- culture medium and, 165
  - as endotoxin producer, 441
  - portals of entry, 431, 431t
  - typhoid fever caused by, 272b, 310, 720–722
  - typhus caused by, 431t
- Salmonella typhimurium*, 719
- antigenic formula for, 310–311
  - Clinical Case, 800b, 802b, 807b, 811b, 813b, 815b
  - membrane ruffling by invasins, 435, 435f
- salmonellosis, 311, 413t, 719–720, 719f, 720f, 728b
- disease reservoirs for, 413t
- incubation period, 431t
- as notifiable infectious disease, 424t
- outbreak (spices/salami), 721b
- portal of exit, 446
- portals of entry, 431t
- transmission due to, 413t
- salpingitis, 758, 758f
- salt. *See also* sodium chloride
- to preserve foods, 189
- salt crystals, formation of, 29, 29f
- salts, 34–36, 34f
- in food preservation, 156, 158, 192
- salty environments
- extreme halophiles and, 4, 158, 274, 274f, 326
  - microbial growth and, 158, 165, 166f
- Staphylococcus aureus* and, 165, 166f
- salvarsan, 12
- SAM (scanning acoustic microscopy), 61, 62f, 66t
- San Joaquin fever. *See* coccidioidomycosis
- sand fly bites, leishmaniasis and, 356t, 665
- sanitization, 182, 183t
- sanitizers
- acid-anionic, 196, 202t
  - hand, 195, 196
- Saprolegnia ferax*, 345f
- saprophytes, 143
- saprophytic molds, 337
- saquinavir, 553, 576
- SAR 11, 303
- Sarcina* genus/spp., 301t
- sarcinae, 77, 77f
- sarcoma, 392
- sarcoma viruses
- chicken/avian, 392, 393
  - feline, 393
  - as oncogenic retroviruses, 393–394
  - rodent, 393
- sarcoptes scabiei* (mite), 60f, 602
- Sargasso Sea, *Pelagibacter ubique* discovered in, 303
- Sargasso Sea brown algae, 343
- Sargassum*, 343
- SARS-CoV (severe acute respiratory syndrome-associated coronavirus), 424t
- SARS (severe acute respiratory syndrome)
- Coronavirus* and, 369, 378t, 424t
  - DNA vaccines and, 258
  - as emerging infectious disease, 419t
- sashimi worms (anisakiasis), 362, 364t
- saturated fatty acids, 39, 39f, 40, 40f
- saturation in substrate concentration, 117, 117f
- sauerkraut
- fermentation and, 134t, 806
  - pH and, 156
- saunas/hot tubs, rashes and, 596–597
- sausage, fermentation and, 134t
- saxitoxins, 346, 446
- scab formation, in inflammatory response, 464f
- scabies, 363, 597b, 607–608, 608f
- ivermectin effective against, 572

- scalded skin syndrome, 441*t*, 593–594, 593*f*
- scanned-probe microscopy, 58*f*, 64, 64*f*, 67*t*
- atomic force microscope (AFM), 58*f*, 64, 64*f*, 67*t*
- scanning tunneling (STM), 64, 64*f*, 67*t*
- scanning acoustic microscopy (SAM), 61, 62*f*, 66*t*
- scanning electron micrograph, defined, 63
- scanning electron microscope (SEM), 63–64, 63*f*, 66*t*
- E. coli* micrograph, 58*f*
- Paramecium* micrograph, 63*f*, 66*t*
- specimen sizes and, 58*f*
- scanning tunneling microscopy (STM), 64, 64*f*, 67*t*
- RecA protein from *E. coli* micrograph, 64*f*, 67*t*
- scar tissue formation, 465
- scarlet fever, 317, 683–684, 686*b*
- exotoxin causing, 442*t*, 677
- portal of exit, 446
- rash of, 439
- Streptococcus pyogenes* causing, 317, 406, 439, 442*t*, 683
- Schaeffer-Fulton endospore stain, 70–71, 70*f*
- Schistosoma* (blood fluke), 358, 364*t*, 668*b*, 674*f*, 675, 738*f*
- Schistosoma haematobium*, 675
- Schistosoma japonicum*, 675
- Schistosoma mansoni*, 675
- schistosomiasis, 330, 358, 364*t*, 673*b*, 674–675, 674*f*, 675*f*
- praziquantel to treat, 577, 675
- schizogony, 348
- in *Plasmodium*, 351–352, 352*f*, 670
- trypanosomes and, 352, 661
- Schizosaccharomyces*, 333–334
- Schulz, Heide, 14
- SCID. *See* severe combined immunodeficiency disease
- scientific applications, of rDNA technology, 260–263
- scientific nomenclature, 2–3, 4*t*, 278
- sclerotic, 445
- scolex of tapeworms, 358, 360*f*
- scrapie disease in sheep, 395, 630
- mad cow disease and, 395
- screening, genetic, 261
- screening procedures for clone selection, 255, 255*f*
- scum, shower, biofilms and, 432
- sea otters, toxoplasmosis deaths, 282*b*, 662
- seafood allergies, 525
- seals
- influenza A viruses and, 18, 374*b*
- phocid distemper virus caused deaths in, 282*b*
- veterinary microbiology and, 282*b*
- seawater microbiota, 783
- sebaceous (oil) glands of skin, 455
- sebum, 455, 474*t*, 590
- secondary immune response, 497, 497*f*
- vaccines and subsequent antigen encounters, 505
- secondary infection, 409
- difficulty in treating in hospitalized patients, 415
- secondary sewage treatment, 789, 790*f*
- secondary structure of proteins, 43, 45*f*
- secretory component, IgA antibody and, 484
- secretory IgA, 484
- secretory vesicles, 102, 104*f*
- seizures, fever and, 466
- selection, 247
- artificial, 247
- of bacteria with resistance factors, 237
- of genetically desirable plants, 263
- natural. *See* natural selection
- selection methods to identify mutations, 229–230, 229*f*
- selective culture media, 165, 167*t*
- identification of microbes and, 284, 285
- selective IgA immunodeficiency, 544*t*
- selective permeability (semipermeability), 90
- selective toxicity principle, 558
- of antibiotics, 553, 555, 557, 558*f*
- tetracyclines, 565
- selenium, nanotechnology and reduced toxicity, 263, 263*f*
- self molecules of MHC, 482, 486, 538
- self-replication capability, DNA vectors and, 249
- self-tolerance loss in autoimmune diseases, 536
- self vs. nonself recognition, 477, 485, 497
- autoimmune diseases and, 536–538
- hyperacute rejection and, 542
- immune system tolerance of fetus and, 539
- major histocompatibility complex (MHC) and, 485, 486, 497, 538–539
- thymic selection and, 486, 536
- transplant rejection and, 539–540
- SEM (scanning electron microscope), 63–64, 63*f*, 66*t*
- E. coli* micrograph, 58*f*
- Paramecium* micrograph, 63*f*, 66*t*
- specimen sizes and, 58*f*
- semiconservative replication, 212
- semipermeability (selective permeability), 90
- semisynthetic penicillins, 564*t*, 567–568, 567*f*
- Semmelweis, Ignaz, 9, 10*f*, 181, 194, 415, 420, 647
- sense codons, 216
- sense strand (+ strand), 388, 388*t*, 389*f*
- sensitivity of diagnostic tests, 512
- sensitized individuals, 523
- sentinel animals, tested for arbovirus antibodies, 630
- sepsis, 182, 409, 416*t*, 646–647, 646*f*
- in cattle, *Pasteurella* and, 312
- cytokine storm and, 497
- endotoxin release with antibiotic therapy for, 640
- gram-negative (endotoxic shock), 646
- gram-positive, 646–647
- Listeria monocytogenes* causing, 620
- lymphangitis and, 639, 640*f*
- neonatal, 647
- Pseudomonas aeruginosa* and, 308
- puerperal (childbirth fever), 647, 649*b*
- severe, 646
- Staphylococcus aureus* causing, 587.
- See also* nosocomial infections
- Streptococcus pyogenes* causing, 595
- septa, 332
- septate hyphae, 332, 332*f*, 340*t*
- septic arthritis, *Haemophilus influenzae* causing, 312
- septic shock, 440, 639–641, 640, 649*b*
- antimicrobial peptides (AMPs) and, 471
- Clinical Case, 479*b*, 480*b*, 484*b*, 487*b*, 490*b*, 494*b*
- septic tanks, 793, 794*f*
- septicemia, 14, 76*b*, 409, 646–647
- Clinical Case, 76*b*, 86*b*, 88*b*, 95*b*, 97*b*
- lymphangitis and, 646, 646*f*
- septicemic plague, 657
- sequencing, DNA, 261–262, 261*f*
- shotgun sequencing, 260, 260*f*
- serial dilution, 171, 172*f*
- serine (Ser), structural formula/characteristic R group, 42*t*
- seroconversion, 516, 543*f*, 545, 550
- serology/serological testing, 286–287, 286*f*, 287*f*, 288*f*, 310, 498
- ELISA test, 286, 287*f*
- slide agglutination test, 286, 286*f*
- tissue typing, 533–534, 533*f*
- virus typing, 512
- Western blotting, 286–287, 288*f*
- serotypes, 14, 286, 310
- of meningococcus, 613
- of *Salmonella enterica*, 310–311
- serovars, 82, 286, 310
- direct agglutination tests and, 510
- of *Salmonella enterica*, 287*b*, 310–311
- of *Vibrio cholerae* 0139, evolution and, 418
- Serratia* genus/spp., 75*f*, 301*t*, 311
- found in catheters/sterile solutions, 311
- Serratia marcescens*, 301*t*, 310, 542
- biofilms and, 153, 153*f*
- serum, 472*b*
- antibody percentages, 479–481, 483*t*
- antibody titer, 493, 494*f*, 510, 511*f*
- antisera and, 286, 498, 498*f*, 616
- fetal calf, 495
- laboratory collection of, 472*b*
- separation of proteins by gel electrophoresis, 495, 495*f*
- serum concentration test, 579
- serum IgA, 484
- serum sickness, 528*t*, 624
- 70S ribosomes, 79*f*, 94, 94*f*, 100*t*
- in chloroplasts, 104
- in mitochondria, 103
- severe acute respiratory syndrome-associated coronavirus (SARS-CoV), 424*t*
- severe acute respiratory syndrome (SARS)
- Coronavirus* and, 369, 378*t*
- DNA vaccines and, 258
- as emerging infectious disease, 419*t*
- severe combined immunodeficiency disease (SCID), 16, 544*t*
- gene therapy to treat, 258
- severe sepsis, 646
- sewage
- bacteria found in, 301*t*, 306, 306*f*
- chlorine gas to disinfect, 194
- Enterobacter* common to, 312
- sewage treatment, 789–795
- aquatic microorganisms and, 776–778
- archaea methanogens used in, 326, 787*f*
- biochemical oxygen demand (BOD), 789
- biofilms and, 161, 787*f*
- disinfection and release, 790*f*, 792
- oxidation ponds, 794
- primary, 789, 790*f*
- secondary, 785*f*, 789–790
- septic tanks, 787–788, 788*f*
- sludge digestion, 790*f*, 792, 793*f*
- Sphaerotilus* and, 306, 306*f*
- tertiary, 794
- Zoogloea* and, 301*t*
- sex (conjugation) pili, 84, 234, 235, 235*f*
- of enterics, 310
- sex pili (conjugation pili), 84, 234, 235, 235*f*
- sexual dimorphism, 360
- sexual recombination, in prokaryotic vs. eukaryotic cells, 100*t*
- sexual reproduction
- in algae, 344, 345*f*
- fungal, 334, 335, 336*f*, 338*f*, 339*f*
- in *Plasmodium vivax*, 351–352, 352*f*
- of protozoa, 349, 349*f*
- sexual spores, 334, 335, 336*f*, 338*f*, 339*f*
- sexually transmitted diseases (STDs), 322, 754. *See also* sexually transmitted infections
- sexually transmitted infections (STIs), 322, 754
- AIDS. *See* AIDS
- bacterial, 754–766, 766*b*, 767*b*
- chancroid (soft chancre), 312, 756, 761*b*
- chlamydia's, 322, 430, 431*t*, 750–751, 761*b*
- epidemics, 20
- genital herpes, 569, 570*f*, 740, 757, 757*f*, 761*b*
- genital warts, 377*t*, 387, 430, 758, 758*f*, 761*b*
- gonorrhea, 307, 754. *See also* gonorrhea
- HIV infection. *See* HIV infection
- lymphogranuloma venereum, 322, 462, 755, 761*b*
- pelvic inflammatory disease, 751–752, 752*f*, 761*b*
- portals of entry, 430, 431*t*, 447*f*
- portals of exit, 446–447, 447*f*
- syphilis, 323, 752. *See also* syphilis
- trichomoniasis, 759*b*, 760, 760*f*
- urethritis, nongonococcal, 322, 750–751, 761*b*
- vaginitis, 756, 756*f*, 759*b*
- vaginosis, 756, 756*f*, 759*b*

- shadow casting technique, 62  
TEM image, 79f
- shampoos, antidandruff, 196
- Sharp, Phillip A., 13t
- sheath, of T-even bacteriophage, 376f, 382f
- sheathed bacteria, 306, 306f
- sheep  
anthrax and, 315  
genetically modified to produce therapeutic drugs, 258, 259t
- scrapie disease in, 395, 636
- sheep scrapie, 395, 636
- mad cow disease and, 637
- shellfish  
paralytic shellfish poisoning (PSP), 346, 356f, 446  
*Vibrio parahaemolyticus* and, 310
- Shiga, Kiyoshi, 10f
- Shiga toxin, 207, 235, 432  
lysogenic phages and, 384, 442  
shigellosis and, 718–719, 718f, 728b
- Shiga toxin-producing *E. coli* (STEC), 207, 235, 384, 442, 711f, 724, 728b
- Clinical Case, 712b, 727b, 728b, 734b, 742b
- as notifiable infectious disease, 424t
- Shigella* genus/spp., 301t, 311, 718f, 719f
- biochemical tests to identify, 137, 284, 284f, 285–286, 285f
- can survive in phagocytes, 462
- directly damaging host cells, 436
- E. coli* O157:H7
- adherence and pathogenicity, 433  
Shiga toxin and, 207, 235, 384, 442, 711f, 723–724, 728b
- as enteric bacteria, 284, 284f, 311
- portals of entry, 431t
- as potential biological weapon, 654b
- shigellosis caused by, 311, 413, 424t, 430, 431t, 718–719
- traveler's diarrhea and, 441t, 724
- uses actin to advantage, 435
- shigellosis (bacillary dysentery), 311, 462, 718–719, 718f, 719f, 728b
- incubation period, 431t
- as notifiable infectious disease, 424t
- portals of entry, 430, 431t
- portals of exit, 446
- Shigella* bacteria causing, 310, 718.  
See also *Shigella*
- waterborne transmission and, 413
- shingles (herpes-zoster), 377t, 394, 396t, 409, 596–597, 596b
- as a latent varicella-zoster virus disease, 394, 396t, 409, 596
- in HIV/AIDS patients, 542, 550t
- rash caused by, 394, 596b, 597f
- vaccine, 503t, 602
- shivering, 466
- shock, 440, 640  
anaphylactic, 524  
endotoxic, 440  
septic, 440, 471, 639–641, 640, 649b
- shoe leather, fungi capable of growing in, 333
- short tandem repeats (STRs), 209
- shotgun sequencing, 260, 260f
- shower door scum as biofilm, 432
- shuttle vectors, 249
- sialic acid, 470
- sickle cell disease, 410  
gene therapy and, 16  
missense mutation and, 225, 225f
- side chain amino acid (tetrapeptide side chain), 85, 85f
- side groups (R groups) of amino acids, 41, 41f, 42t
- siderophores, 436, 436f, 447f  
enterobactin and, 436f  
iron-binding proteins and, 473
- signals (chemical)  
as alarm signals (alarmones), 221, 222f  
biofilms and, 56b, 161
- signs, vs. symptoms, 408
- silencing, gene, 258, 258f
- silent (neutral) mutations, 224
- silica, in cell walls of diatoms, 345t, 346
- silk worm disease, Pasteur's work on, 9
- silver  
as an antiseptic, 195–196, 195f, 202t  
impregnated in dressings, indwelling catheters, 195
- silver-haired bats, rabies virus variant associated with, 628, 631b, 631f
- silver nitrate, 195, 202t, 610
- silver-sulfadiazine, 195, 202t, 567, 594
- simian AIDS, 379
- simian immunodeficiency virus (SIV), 545
- simple carbohydrates, 37
- simple diffusion, 91, 91f
- simple lipids, 39–40, 39f
- simple proteins, 44
- simple stains, 67–68, 71t
- simple sugars, 37
- Simplexvirus* (HHV-1, HHV-2), 377t, 387, 394, 396t
- Sin Nombre hantavirus, 660, 667b
- single-stranded DNA nonenveloped viruses, 377t
- single-stranded DNA viruses, 388t
- single-stranded RNA, + strand enveloped viruses, 377t, 378t, 388t
- single-stranded RNA, + strand nonenveloped viruses, 377t, 378t, 388t
- singlet oxygen, 159, 462
- sunlight and, 190
- sinusitis, 682–683
- siRNAs (small interfering RNAs), 258, 258f, 579
- sirolimus (Rapamune), 542
- SIRS (systemic inflammatory response syndrome), 646
- site-directed mutagenesis, 247
- SIV (simian immunodeficiency virus), 545
- sizes, of viruses, 372f
- skin, 453, 453f, 589–609  
acidity of, 453  
broken, susceptibility to infections, 416, 417t, 451  
cancers, UV light and, 228  
chemicals that defend, 453, 474t, 589  
commensal microbes of, 453  
delayed hypersensitivity reactions and, 530–531, 530f, 531b, 532f  
dermis of, 451, 451f, 474t, 590, 590f  
epidermis of, 451, 451f, 474t, 590, 590f  
as first line of defense, 452f, 453, 474t, 489  
function of, 584, 590  
immune system and, 453–456, 474t  
infections transmitted from, 447  
keratin and, 340, 340t, 404t, 451, 451f  
lesions, 587f, 591  
microbial diseases of, 589–609  
bacterial, 451, 591–600  
caused by *Streptococcus pyogenes*, 406  
cutaneous mycoses and, 340, 340t  
fungal, 605–607  
hookworm larvae and, 430  
nosocomial, 417t  
parasitic infestations of, 607–609  
staphylococcal, 2b, 17b, 19b, 20b, 21b, 316, 591–594, 592f, 593f  
streptococcal, 594–596, 595f  
viral, 600–605  
normal microbiota of, 316, 404t, 591  
innate immunity and, 452f, 453, 455–456  
perspiration flushes microbes from surface, 455  
pH of, 453, 591  
as physical barrier to pathogens, 452f, 453–455, 453f, 474t, 584  
as portal of entry, 430, 431t, 447f  
as portal of exit, 446, 447, 447f  
*Propionibacterium* bacteria on, 319  
rashes. See rashes  
regeneration capacity of, 465  
sebum and, 455, 590, 590f  
structure of, 590, 590f  
sweat glands and perspiration, 455, 590f  
waterproofed by keratin, 590
- skin tests  
for antigen sensitivities, 531, 531f  
for food allergies, 531  
for leprosy, 620  
patch test for dermatitis cause, 535  
for penicillin sensitivity, 530  
for tuberculosis, 507, 535
- skunks  
as disease reservoirs, 413t  
reported cases of rabies in, 630f  
slants, defined, 162
- SLE (St. Louis encephalitis), 378t, 630, 634b
- sleeping sickness. See trypanosomiasis
- slide agglutination test, 286, 286f
- slime  
*Beggiatoa alba* and, 307  
biofilms and, 17, 18f, 56b, 160–161, 161f  
*Zoogloea* and, 307  
slime layer, 80, 100t, 304f. See also biofilms  
catheters and, 18f, 586, 587f  
slime molds, 4, 6, 353–354, 354f, 355f  
position in evolutionary tree, 274f
- slime trails, *Myxococcus* bacteria and, 56b, 313, 313f
- slow-growing mycobacteria, identification tests for, 142b
- sludge, 789–793
- sludge digestion in sewage treatment, 326, 790f, 792–793, 793f
- small interfering RNAs (siRNAs), 258, 258f, 579
- small intestine, 459f  
enzymes, most microbes destroyed by, 430  
parasitic helminths and, 364t
- small nuclear ribonucleoproteins (snRNPs), 211t, 218, 219f
- smallpox vaccine, 506t, 601  
cowpox virus and, 11, 505  
early experiments to develop, 11, 406, 505  
as first vaccine, 477  
importance to science of immunology, 505  
variolation procedure and, 505
- smallpox (variola), 377t, 596b, 600–601, 601f  
as a biological weapon, 596, 654b  
cidofovir may be effective against, 575, 601  
early epidemics, 11, 505  
first disease for which vaccine was developed, 477  
mortality rate in 18th century, 505  
as notifiable infectious disease, 424t  
orthopoxvirus causing, 376f, 377t, 595  
portal of entry, 430  
portal of exit, 446  
Poxviridae causing, 387  
rash caused by, 596b  
vaccine. See smallpox vaccine  
varicella virus confers immunity to, 505  
variola major/minor forms of, 600
- smallpox (variola) virus. See smallpox (variola)
- smear (specimen), 67
- Smith, Hamilton, 10f, 227
- Smith, Theobald, 673
- smooth ER, 98f, 102, 103f
- Smoothbeam treatment, to treat acne, 600
- smuts, 340t
- snails, freshwater, 364t
- Snow, John, 420
- snRNPs (small nuclear ribonucleoproteins), 211t, 218, 219f
- soaps and detergents, 196, 196f, 202t
- SOD (superoxide dismutase), 159, 159t, 473b  
genetically modified, 259t
- sodium azide, resistance to by gram-negative vs. gram-positive bacteria, 87t
- sodium benzoate, 197, 202t
- sodium chloride (NaCl)  
dissociation of, 34, 34f  
formation of, 29, 29f  
*S. aureus* and selective culture media, 165, 166f  
water acting as solvent for, 34, 34f



- sodium dichloroisocyanurate, 194  
sodium hydroxide (NaOH)  
  as a base, 34, 34f  
  autoclaving and, to destroy prions, 200  
  colony hybridization and, 257f  
sodium hypochlorite (Clorox/chlorine compound), as disinfectant, 193f, 194  
sodium (Na)  
  atomic number/atomic weight, 27t  
  as ion, 29, 29f, 34, 34f  
sodium nitrate/nitrite  
  as food preservatives, 197, 202t  
  as meat preservative, 197  
sodium thioglycolate, in reducing media, 163  
sudoku (rat bite fever), 655  
soft chancre (chancroid), 756, 761b  
soft-rot diseases of plants, *Erwinia* bacteria as cause, 311  
soil  
  as disease reservoirs, 306–307, 309, 311, 317–318, 319, 319f, 320, 322, 411, 646, 668b  
  DNA probes to identify specific, 261  
  pathogenic fungi in, 340–341, 340t, 342b  
  protozoa inhabit, 348  
  screening for antibiotic-producing microbes, 560  
soil bacteria  
  actinomycetes, 318–320  
  *Azomonas* and, 309  
  *Azospirillum*, 303–304  
  *Azotobacter*, 309  
  *Burkholderia pseudomallei*, 306–307  
  *Enterobacter*, 312  
  *Klebsiella*, 311  
  *Pseudomonas*, 307–309  
  rhizobias and, 304–305  
  streptomycetes, 319–320, 319f  
soil microbiology  
  biogeochemical cycles and, 775–782.  
  See also specific cycles  
  life without sunshine, 779–780  
  synthetic chemicals and, 780–782  
soil microbiota  
  beneficial, 2  
  pathogenic fungi in, 340–341, 340t  
soil samples, enrichment mediums and, 166  
solar evaporating ponds, extreme halophiles (archaea) found in, 326  
solid municipal waste (garbage), 781–782  
solutes, 34  
solutions  
  acidic vs. alkaline, 34, 35f  
  hypertonic, 92f, 93, 156, 157f  
  hypotonic, 92f, 93, 157f, 158  
  isotonic, 92f, 93, 157f  
solvents, 34, 34f  
somatostatin  
  chemically synthesized genes and, 254  
  genetically modified *E. coli* and production of, 257  
sorbic acid, 197, 202t  
sorbitol  
  fermentation and, 134t  
  fermentation by *E. coli* and, 136, 137f  
sorbse, as fermentation end-product, 134t  
sore throat  
  caused by *Streptococcus pyogenes*, 406  
  *Streptococcus pyogenes* and, 317  
sound waves, scanning acoustic microscopy and, 61, 62f, 66t  
Southern blotting, 261, 262f, 290, 291f, 292  
soy products, food allergies and, 525  
soybeans  
  *Coniothyrium minitans* and, 341  
  *Phytophthora infestans* infests, 347–348  
Spallanzani, Lazzaro, 7  
special stains/staining, 69–71, 70f, 71t  
specialized transduction  
  in bacteria, 235, 384  
  lysogeny and, 384, 384f  
species barrier  
  antigenic shift and, 374–375b  
  influenza A virus crossing, 374–375b  
species name (specific epithet)  
  defined, 3, 278  
  eukaryotic vs. prokaryotic, 278–280  
  viral, 281  
specific epithet (species name),  
  defined, 3, 278, 279f  
specificity  
  of antibodies, 487  
  of enzymes, 113–114, 116  
  specificity and diagnostic tests, 512  
specimen preparation, 53, 67. See also stains/staining  
  artifacts and, 63  
  size, microscope resolution and, 58f  
spectrophotometers  
  endotoxin testing and, 441  
  to measure turbidity, 175, 176f  
spectrums of antimicrobial activity, 560–561, 562t  
*Sphaerotilus* genus/spp., 300t, 306, 306f  
  as sheathed bacteria, 300t  
*Sphaerotilus natans*, 306, 306f  
spherical-shaped bacteria, 77–78, 78f  
spheroplasts, 88  
spice-associated foodborne illnesses, 721b  
spicules of nematodes, 360, 362f  
spikes (viral), 371, 373, 373f  
  gp120 glycoproteins on HIV, 545, 546f, 553  
  Influenzavirus, 378t, 692–693, 692f  
spinal cord, 611, 611f  
spinal tap (lumbar puncture), 619, 620f, 621b  
spiral-shaped bacteria, 77, 78, 78f  
spirilla/spirillum, 78, 78f  
spirillar fever (rat bite fever), 655  
*Spirillum* genus/spp., 95, 301t, 306, 306f  
*Spirillum minus*, causing rat bite fever (spirillar fever), 555b, 655  
*Spirillum volutans*, 306, 306f  
  flagella staining of, 70, 71t  
Spirochaetales, 302t  
Spirochaetes, 302t  
spirochetes, 78, 78f, 106b, 325, 325f  
  axial filaments (endoflagella) of, 82, 83f, 325, 325f  
  Lyme disease and, 362  
  motility of, 82, 83f, 325, 325f  
  phylogenetic relationships, 280f  
*Spiroplasma* genus/spp., 301t, 318  
spleen, 459, 459f  
  immune response and, 490b, 494b  
  in monoclonal antibody production, 508f  
spoilage  
  alcoholic beverages and, 9  
  food. See food spoilage  
sponges, as eukarya, 6  
spongiform encephalopathies, prions and, 200, 395, 630f  
spontaneous generation theory, 6–8  
  disproving (Foundation Figure), 9f  
spontaneous mutations, 225  
  frequency of, 228, 237  
sporadic disease, 406  
sporangia  
  of *mucor*, 5f  
  of plasmodial slime mold, 355f  
sporangioles, 313f  
sporangiophores, 333  
sporangiospores, 335, 335f, 340t  
  of *Rhizopus*, 335, 336f  
sporangium (spore sac), 335, 335f  
spore caps, of cellular slime molds, 353, 354f  
spore clusters, of *M. xanthus* cells, 56b, 56f  
spore coat, 96f, 97  
spore sac (sporangium), 335, 335f  
spore septum, 96f, 97  
spores (endospores), 70, 70f, 71f, 96, 332  
spores (fungal), 281, 331f, 332f, 333f, 334–335  
  airborne transmission and, 339, 413  
  asexual, 331f, 334–335, 335f, 336f, 337f, 338f, 339f  
  chemical biocides resistance and, 203f  
  endospores vs., 70, 332  
  growth of hyphae from, 332, 332f  
  reproductive, 331f, 332  
  sexual, 331f, 334, 335, 336f, 338f, 339f  
  in slime molds, 353, 354f, 355f  
  systemic mycoses and, 339  
  zygospores, 333, 335f  
sporicidal agents, peracetic acid, 202  
sporides  
  glutaraldehyde, 197, 201t, 202t  
  hydrogen peroxide, 202  
*Sporothrix schenckii*, 340t, 597b, 606  
sporotrichosis, 340, 597b, 606  
sporozoite, 351, 352f  
  *Plasmodium* and, 351, 352f  
  in toxoplasmosis, 661, 662f  
sporulation/sporogenesis, 96–97, 96f  
  evolutionary development, 315  
  reproduction and, 97  
spotted fevers, 661. See also Rocky Mountain spotted fever  
  as nationally notifiable infectious diseases, 424t  
  rickettsiosis, 304  
spread plate method of plate counts, 172, 173f  
squalamine, 585  
squid, *anisakines* roundworms and, 362, 364t  
squirrels  
  plague and, 657–658  
  plague carried by, 311, 656b, 657–658  
  tularemia carried by, 648, 656b  
src gene, cancer-causing, 393  
SSPE. See subacute sclerosing panencephalitis  
St. Louis encephalitis (SLE), 377t, 630, 634b  
  as an arbovirus, 625, 628b  
  *Culex* mosquito as vector, 628b  
*Stachybotrys*, 340t, 341, 445  
stains/staining, 67–71, 71t  
  counterstains, 68f, 69, 71  
  decolorizing agents, 68f, 69  
  differential, 68–69, 68f, 70f, 71t  
  electron microscopes and, 62–63  
  endospore, 70–71, 70f, 71t  
  fixing specimen to slide, 67  
  flagella, 62, 70f, 71, 71t  
  Gram stain, 68–69, 68f, 71t, 86, 87t  
  negative, 62, 69, 70, 71t  
  positive, 62  
  preparing specimen for, 67  
  primary stain, 69  
  refractive index and, 57  
  simple, 67–68, 71t  
  smears and, 67  
  special, 69–71, 71f, 71t  
  stalked-cell bacteria, 300t, 303, 304f  
Stanier, Roger, 273  
Stanley, Wendell, 14, 370  
staphylococcal enterotoxigenesis, 717–718, 717f, 728b  
staphylococcal enterotoxin, 433, 439, 441t, 442  
staphylococcal skin infections, 2b, 17b, 19b, 20b, 21b, 591–594  
staphylococci, 77, 77f. See also *Staphylococcus* genus/spp.  
  disinfectants effective against, 196, 196f  
  most likely to cause skin infections, 451  
  nosocomial infections and, 415, 416t, 423b  
  pathogenic characteristics, 316  
*Staphylococcus aureus*, 1, 1f, 316, 316f  
  acute inflammation caused by, 463  
  adherence mechanism resembles viral attachment, 433  
  antibiotic resistance and, 18, 19b, 20, 20b, 316  
  biochemical tests and, 137f, 282b  
  biofilms and catheters, 17, 18f  
  cellulitis caused by, 598b  
  as coagulase-positive, 587  
  culture media to identify, 165, 166f  
  destroying a phagocyte, 76f  
  disinfectants and, 193f  
  endocarditis caused by, 647, 649b  
  enterotoxins produced by, 316, 437, 441t

- fluorescent in situ hybridization and, 293f
- food poisoning caused by, 316, 441t, 717–718, 717f, 728b
- gastric juice unable to destroy, 455
- health care-associated, 415, 416t
- impetigo and, 593, 593f
- methicillin-resistant, 207. *See also* MRSA
- as most pathogenic staphylococci, 586–589
- as normal microbiota of eye, 404t
- as normal microbiota of nose, throat, 1, 1f, 404t, 592–593
- as normal microbiota of skin, 17b, 404t
- nosocomial infections and, 415, 416t, 423b
- otitis media caused by, 685
- penicillin resistance, 18, 316
- postoperative eye infections and, 559b
- scalded skin syndrome caused by, 441t, 593–594, 593f
- skin infections and, 2b, 17b, 19b, 20b, 592–594, 593f, 594f, 596b, 597b
- staphylokinase produced by, 434
- superantigens produced by, 439
- as superbug, 580
- toxic shock syndrome and, 316, 439, 594, 597b
- toxins produced by, 235, 316, 439, 441t
- vancomycin-intermediate resistant (VISA), 18, 419t, 423b, 424t
- vancomycin-resistant (VRSA), 12, 18, 207, 237, 419t, 423b, 424t, 563
- Staphylococcus epidermidis*, 405f
- as a nosocomial pathogen, 592, 592f
- catheters, biofilms, and, 592, 592f
- in differential culture media, 165, 166f
- fermentation test to detect, 137, 137f
- as normal microbiota of eye, 404t
- as normal microbiota of nose, throat, 404t
- postoperative eye infections and, 559b
- skin infections and, 591–592, 592f
- symbiotic relationships (commensalism) of, 405, 405f
- Staphylococcus genus/spp.*, 18, 301t, 314, 316, 316f
- fermentation test to detect, 137, 137f
- genetic transformation natural occurrence in, 23
- leukocidins produced by kill phagocytes, 462
- as normal microbiota of mouth, 404t
- as normal microbiota of skin, 404t
- as normal microbiota of urethra, 404t
- Staphylococcus saprophyticus*, cystitis caused by, 752
- staphylokinase, produced by *Staphylococcus aureus*, 434
- star-shaped bacteria, 78, 78f
- starch granules, in presence of iodine, 95
- starches, 38
- as carbohydrates, 38
- stored by green algae, 345t, 346
- start codons, 209, 215f, 216f
- stationary phase in bacterial growth, 170–171, 170f
- STDs. *See* sexually transmitted diseases
- steam heat, to control microbial growth, 185–187, 186f, 186t, 191t
- stearic acid, 39f
- STEC. *See* Shiga toxin-producing *E. coli*
- Steitz, Thomas A., 13t
- Stella* genus, 78, 78f
- stem cells
- adult, 540
- bone marrow, B cells, T cells
- originate from, 486, 486f
- embryonic (ESCs), 540, 540f
- as part of lymphatic system, 458
- transplantation medicine and, 540
- umbilical cord blood cells, 540
- stents, cardiovascular
- biofilms colonizing, 431
- sirolimus (Rapamune) to prevent rejection, 542
- stereoisomers, 41, 42f
- sterilants, 182, 198
- ethylene oxide, 198, 202t
- glutaraldehyde, 197, 201t, 202t
- hydrogen peroxide, 199, 202t
- peracetic acid, 199, 202t
- sterile culture media, 162
- sterilization, 182, 183t. *See also* sterilants
- autoclaves and, 185–187, 186f, 186t, 191t, 441, 442b, 444b
- by boiling water, 185
- calculating time necessary for, 185, 186t
- chemical, 198–199, 202t
- commercial, 182, 183t, 187, 794–795, 794f, 795f
- endotoxins survival despite, 439, 444b
- by flaming (dry heat), 188
- of gases, 182
- by gases, 183t
- by hot-air, 188
- indicators of successful, 187, 187f
- of liquids, 182
- of milk, by UHT treatments, 187
- by moist heat, 185–187, 191t
- plasma, 201
- by radiation, 189–190, 190f, 191t
- reliable temperatures for, 185
- viruses and, 185
- steroid injections, infection following (Clinical Focus), 198b
- steroids, 41, 41f
- synthesized from microbes, 806, 806f
- sterols, 41, 41f, 87, 89, 100, 100t
- antifungal drugs affecting, 564t, 574, 574f
- in fungi plasma membrane, 333t, 558
- in *Mycoplasma* plasma membrane, 41, 41f, 87, 89
- Stewart, Sarah, 10f, 392
- sticky ends of cut DNA strands, 247–248, 248f
- replication and, 211t
- transposase and, 238f
- Stigmatella* genus/spp., 301t
- stipes of algae, 344, 344f
- STIs. *See* sexually transmitted infections
- STM (scanning tunneling microscopy), 65, 65f, 67t
- E. coli* RecA protein micrograph, 64f, 67t
- specimen preparation and, 65
- stomach
- enzymes destroy most microbes (except some toxins), 430, 455
- gastric juice, 455
- stomach cancer, *Helicobacter pylori* and, 719
- “stone-washed” denim jeans (Applications of Microbiology), 3b, 38
- stool samples
- differential media and, 273b, 286b, 287b, 290b, 293b, 294b
- enrichment mediums and, 166, 286b, 287b
- stool DNA test, 208b
- stop codons (nonsense codons), 209, 215f, 216–218, 216–217f
- storage materials, of algae, 345t
- storage vesicles, 103
- strains (bacterial)
- of bacterial species, 280
- Bergey’s Manual* and, 286
- improvements, industrial microbiology active in, 803
- phage typing to distinguish, 287, 289f
- serological testing to identify, 286
- Stramenopila (kingdom), 346
- strand (antisense strand), 388, 389f
- strand, multiple strands of RNA viruses, 378t
- strand, one strand of RNA viruses, 378t
- strand RNA viruses, 388t
- + strand RNA viruses, 388t
- strand RNA viruses, 388t
- + strand RNA viruses, 389f
- strand RNA viruses, 389f
- + strand RNA viruses, 389f
- + strand (sense strand), 388, 388t, 389f
- stratum corneum, 590, 590f
- streak plate method, 167, 167f
- strep throat (streptococcal pharyngitis), 165, 683, 683f, 686b
- streptococcal M proteins, 591
- streptobacillary rat bite fever, 655, 655b
- streptobacilli, 77, 77f
- Streptobacillus* genus/spp., 302t
- Streptobacillus moniliformis*, streptobacillary rat bite fever caused by, 655, 655b
- streptococcal infections
- of skin, 594–596, 595f
- strep throat, 165, 683, 683b, 683f
- sulfa drugs effective against during WWII, 559
- streptococcal pharyngitis (strep throat), 165, 683, 683b, 683f
- streptococci, 14, 77, 77f
- alpha-hemolytic streptococci, 317
- beta-hemolytic (group A, B), 317, 320b
- dairy industry and, 317
- disinfectants effective against, 196, 196f
- enzymes produced by, tissue destruction and, 286, 317
- group A (GAS), 317, 594–596, 595f, 640
- invasive group A (IGAS), flesh-eating bacteria and, 19, 595–596
- group B (GBS), 317, 320b, 324b, 647
- identification via immunological techniques, 14, 286
- lysogenic phages, toxic shock syndrome and, 384
- M protein and, 317, 590–591, 591f
- non-beta-hemolytic, 317
- as normal microbiota of eye, 404t
- serotypes of, 14, 286
- streptolysin released by kills phagocytes, 462
- viridans streptococci*, 317
- Streptococcus agalactiae*, 299f, 317, 320b, 647
- neonatal sepsis caused by, 317, 320b, 324b, 647
- Streptococcus equisimilis* H46A, 434b
- Streptococcus faecalis*, 279, 317
- Streptococcus faecium*, 279, 317
- Streptococcus* genus/spp., 301t, 314, 316–317, 316f
- as chemoheterotroph, 143f
- fermentation and, 132f, 133, 134t, 135b
- genetic transformation natural occurring in, 233
- as lactic acid bacteria, 133
- low G + C content and, 314
- as normal microbiota of mouth, 135b, 404t
- as normal microbiota of vagina, 404t
- penicillinase-producing plasmid and *Neisseria*, 237
- Streptococcus mutans*, 317, 432, 441
- Actinomyces*, dextran, and dental plaque, 432, 707
- dental caries and, 80, 112b, 133b, 135b, 137b, 317, 713–714, 714f, 716b
- glucosyltransferase produced by, 431
- glycocalyx of, 80
- Streptococcus pneumoniae*
- capsule of, virulence and, 232, 433, 442, 508
- classification changes and, 278
- DNA transformation process and, 232–233, 233f, 234f
- drug-resistant, as notifiable infectious disease, 424t
- emerging infectious diseases and, 419t
- evasion of phagocytosis and, 462
- Griffith’s experiments with, 232–233, 233f
- incubation period for, 431t

- meningitis (pneumococcal)  
caused by, 317*b*, 612, **614**, 623*b*  
nonencapsulated, avirulent strain of,  
232, 433  
as normal microbiota of nose,  
throat, 404*t*  
as notifiable infectious disease,  
424*t*  
as opportunistic pathogen, 406  
otitis media caused by, 685  
pneumococcal pneumonia caused  
by, 14, 317, 431*t*, 433, **693**,  
**693f**, **695b**  
portals of entry, 431*t*  
post-influenza bronchopneumonia  
caused by, 409  
resistance to beta-lactam  
antibiotics, 581  
vaccine, 506*t*, 508, 614  
virulence and, 80, 232–233, 233*f*,  
433, 441  
*Streptococcus pyogenes*, 4*t*, 317,  
590–591, 591*f*  
childbirth caused by, 420, 647, 649*b*  
differential media to identify, 165,  
166*f*, 317  
diseases caused by, 317, 406, 407  
erythrogenic toxin and, 235  
ethanol effectiveness against, 194*t*  
evasion of phagocytosis and, 462  
as “flesh-eating” bacteria, 20, 286,  
317, 321, 423*b*, 591, 591*f*  
impetigo and, 593, 593*f*  
iron source for, 473  
M protein and, 317, 433, 462,  
595, 595*f*  
as most important beta-hemolytic  
streptococci, 595  
otitis media caused by, 685  
pericarditis caused by, **647**, **649b**  
serotypes of, 286  
strep throat caused by, 683,  
683*f*, 686*b*  
streptokinase produced by, 434,  
434*b*, 590, 677  
toxic shock syndrome and, 384,  
419*t*, 424*t*  
*Streptococcus salivarius*, 135*b*  
*Streptococcus sobrinus*, 135  
*Streptococcus thermophilus*, used to  
make yogurt, 799  
streptogramins, 565*t*, **571**  
streptokinase (fibrinolysin), 434, 434*b*,  
595, 683  
streptolysin O (SLO), 439  
streptolysin S (SLS), 439  
streptolysins, **439**, 462, 595, 683  
*Streptomyces venezuelae*,  
chloramphenicol derived  
from, 560*t*  
*Streptomyces*, vancomycin derived  
from, 563  
*Streptomyces aureofaciens*,  
chlortetracycline, tetracycline  
derived from, 560*t*  
*streptomyces avermectinus*, ivermectin  
derived from, 566*t*, 577  
*Streptomyces fradiae*, neomycin  
derived from, 560*t*  
*Streptomyces* genus/spp., 302*t*, 318,  
**319**–320, 319*f*  
actinomycetes informal name for,  
318–319  
antibiotics derived from, 302*t*,  
560*t*, 563  
vancomycin, 563  
antibiotics produced by, 320  
G + C content of, 314  
as pleomorphic bacteria, 320  
reproductive asexual spores of, 320  
used in production of steroids,  
806, 806*f*  
*Streptomyces griseus*, streptomycin  
derived from, 560*t*  
*Streptomyces nodosus*, amphotericin B  
derived from, 560*t*  
streptomycin, 561*f*, 562*t*, 565*t*, **570**  
derived from *Streptomyces*  
*griseus*, 560  
protein synthesis inhibited by, 94,  
556–557, 558*f*, 561*f*, 562*t*, 563*f*,  
565*t*, 570  
resistance factors and, 236, 238*f*  
susceptibility of gram-negative vs.  
gram-positive bacteria to, 87*t*  
stroke, hemorrhagic, genetically  
modified Factor VII to  
treat, 259*t*  
stroma, 465  
stromatolites, 277, 277*f*  
STRs (short tandem repeats), **209**  
sty, **593**  
subacute bacterial endocarditis, **647**,  
647*f*, **649b**  
subacute disease, **409**  
subacute sclerosing panencephalitis  
(SSPE), 394, 396*t*, 409, **604**  
subarachnoid space, 616, 617*f*  
subclavian veins, 459*f*  
subclinical infection (inapparent  
infection), **409**  
subcutaneous mycoses, 340–341, 340*t*,  
**601**, **606**  
sublimation, in preserving bacterial  
cultures, 168  
sublittoral zone, algal habitats, 344*f*  
substrate, **113**, 114*f*  
concentration of, 116, **117**, 117*f*  
substrate-level phosphorylation, **120**,  
124, 135*t*  
aerobic respiration and, 135*t*  
ATP yield, 130*t*  
in Krebs cycle, 126, 126*f*  
subunit vaccines, **257**, **508**  
subunits of ribosomes, 94, 94*f*, 101  
succinic acid, 126*f*, 132*f*, 147*f*  
succinyl CoA, 147*f*  
sucking lice, 363, 364*t*  
sucrase, 115*t*  
sucrose (table sugar), 39, 39*f*  
saliva pH decreased by, 133*b*  
Sudan dyes, 95  
sudden oak death, 348  
sugar-phosphate backbone of DNA,  
208, 214*f*, 215*t*, 248, 248*f*  
sugar (table), fermentation and, 134*t*  
sugars  
as carbohydrates, 37–38  
carbon dioxide in synthesis of,  
138, 141*f*  
deoxyribose, 46*f*, 47  
milk (lactose), 38  
simple, 38  
table (sucrose), 38, 38*f*  
sulfa drugs. *See* sulfonamides  
sulfadiazine, 195  
sulfamethoxazole, 565*t*, 573, 573*f*  
sulfanilamide, 558, 561*f*  
as antimetabolite to PABA, 558,  
563–564  
as an enzyme inhibitor, 118  
sulfate ion (SO<sub>4</sub><sup>2-</sup>), 130, 158  
sulfate-reducing bacteria,  
*Desulfovibrio*, 301*t*  
sulfhydryl functional group, 36, 36*t*, 41  
sulfites, allergic reactions to, 531  
Sulfolobales, 302*t*  
*Sulfolobus* genus/spp., 302*t*, **326**  
sulfonamides (sulfa drugs), 12, 553,  
559, **567**, 568*f*  
bacterial resistance to, 236, 238*f*  
as an enzyme inhibitor, 118  
mode of action/spectrum of  
activity, 563*t*  
susceptibility of gram-negative vs.  
gram-positive bacteria to, 87*t*  
sulfone drugs, to treat leprosy, 626  
sulfur bacteria, defined, 324  
sulfur cycle, 779, 780*f*  
anaerobic respiration and, 130  
bacteria important to, 306,  
312–313, 774*f*  
deltaproteobacteria and, 312–313  
sulfur dioxide, as food additive, 197  
sulfur granules, 95, 321*t*  
sulfur-oxidizing bacteria, 300*t*, 301*t*, 306  
sulfur-reducing bacteria, 312–313  
sulfur (S)  
acidophiles and, 156  
atomic number/atomic weight, 27*t*  
chemoautotrophic bacteria and, 156  
in cysteine (amino acid), 42*t*, 45  
deltaproteobacteria and, 312–313  
electronic configuration, 28*t*  
as an energy source for bacteria, 139,  
141*f*, 143, 143*t*, 306  
green bacteria and, 142, 143*t*  
in methionine (amino acid), 42*t*  
microbial growth requirements, 158  
in organic compounds, 36  
sources of, 158  
*Thiobacillus* and, 35, 306  
sulfuric acid  
chemoautotrophic bacteria and, 156  
*Thiobacillus ferrooxidans* and, 35  
summer sausage, fermentation and, 134*t*  
sunlight  
antimicrobial effect of, 190  
life without, 779–780  
sunscreens, genetically modified  
melanin in, 258  
suntanning, skin cancers and, 227–228  
superantigens, **439**, 441*t*, 497, 527, 589  
erythrogenic toxins as, 439  
superbugs, **580**  
supercritical carbon dioxide, 199, 202*t*  
superficial mycoses, **340**  
superinfections, **561**  
tetracyclines use often leads to, 571  
superoxide anions, **159**  
superoxide dismutase (SOD), **159**,  
159*t*, 473*b*  
genetically modified, 259*t*  
superoxide radicals, **159**, 462, 472*b*, 473*b*  
suppressor T cells. *See* T regulatory cells  
suramin, 627  
surface-active agents (surfactants), as  
antimicrobial agents, 192, 193*f*,  
**196**–197, 196*f*, 201*t*, 202*t*  
Surfactine, 195  
surfactants. *See* surface-active agents  
surgery  
brown alga *Laminaria japonica*  
and, 346  
nosocomial infections and, 422*b*  
surgical dressings, in nosocomial  
infections, 416, 417  
surgical gloves, latex allergy and,  
530–531  
surgical hand scrubs, 193, 201*t*  
surgical infections  
*Bacteroides* and, 322  
phage typing to trace, 287, 289*f*  
surgical instruments  
endotoxins and, 442*b*, 444*b*  
prion contamination, protease  
enzymes to inactivate, 200  
surgical wounds  
aseptic techniques and, 181  
body's normal defenses, sterilization  
and, 182  
early attempts to control infection  
in, 11  
infections  
microbes causing, 416*t*  
phage typing to trace, 287, 290*f*  
*Staphylococcus aureus* and, 316  
at surgical site, 417*t*  
MRSA-infected patients post-  
surgery, 423*b*  
nosocomial infections and, 416*t*, 417*t*  
susceptibility, **451**  
susceptibility testing for antibiotics,  
577–579, 751*b*  
broth dilution test, **578**–579, 579*f*  
disk-diffusion method, 578, 578*f*  
E test, **578**, 578*f*  
Svedberg units, 94  
swarming, in bacterial motility, 81,  
82*f*, 311*f*  
swarming bacteria, *Proteus*, 82, 311, 311*f*  
sweat glands, 590, 590*f*  
dermicidin produced by, 473  
sweat (perspiration), **455**, 590, 590*f*  
sweat/sweating  
antimicrobial properties, 404*t*  
fever and, 466  
glands in skin, perspiration and, 455  
swelling (edema), of inflammation, 463  
swimmer's ear (otitis externa),  
597*b*, **598**  
swimmer's itch, **673b**, **675**  
swimming pools  
chlorine gas used to disinfect, 194  
conjunctivitis from, 610  
otitis externa and, **599**  
rashes and, 596, 598–599, 599*b*,  
605*b*, 607*b*, 611*b*  
swine, as disease reservoirs, 377*b*, 413*t*  
swine flu (H1N1 influenza virus), **18**,  
374–375*b*, 405*f*  
Swiss cheese  
fermentation and, 134*t*, 137, 320, 799  
how holes are formed, 137



- Sydenham's chorea (Saint Vitus' dance), **648**
- symbionts of insects, **300t**
- symbiosis, **105**, **106b**, **266**, **405**, **405f**, **773**
- algae and giant clams, **348**
- mycorrhizae fungi and, **330**
- nitrogen fixation process and, **158**
- between normal microbiota and host, **405**, **405f**
- ruminants and, **767**
- truffles and, **773**, **774f**
- symbiotic bacteria, **266**, **300t**, **302t**, **303**
- Carsonella ruddii*, **327**
- genetically modified *Rhizobium* and, **266**
- rhizobias and, **304**–**305**
- Wolbachia* and, **306**, **308b**
- symbiotic fungi (mycorrhizae), **330**
- symptoms, vs. signs, **408**
- Synagis (palivizumab), **692**
- syncytium, **443**, **444f**, **692**
- syndrome, **408**
- Synechococcus*, **777**
- Synercid (dalbapristin), mode of action/spectrum of activity, **562t**
- Synercid, **565t**, **571**
- synergism, **584**, **584f**
- of antimicrobial peptides (AMPs), **473**
- in combination antibiotics, **571**, **573f**, **584**, **584f**
- synthesis reactions, **32**
- synthetic DNA, **253**–**254**, **254f**
- used to produce human insulin, **257**
- synthetic drugs, **11**–**12**
- synthetic genes. *See* synthetic DNA
- synthetic rubber, **257**
- syphilis, **20**, **325**, **325f**, **758**–**762**, **759f**, **760f**, **767b**. *See also* *Treponema pallidum*
- central nervous system affected by late-stage, **754**
- chancres of, **760**, **760f**
- congenital, **424t**, **761**
- culturing issues with, **164**
- culturing media and, **167**, **406**
- diagnosis of, **57**, **59**, **61f**, **66t**, **761**
- gummas of, **760f**, **761**
- incidence and distribution, **20**, **759**–**760**, **759f**
- incubation period, **431t**, **760**
- latent period, **761**
- as notifiable infectious disease, **424t**
- portals of entry, **430**, **431t**, **770**
- pregnancy and, **760**, **761**
- progression of
- primary stage, **760**, **760f**
  - secondary stage, **760**, **760f**
  - tertiary (late-stage), **760f**, **761**
- rashes of, **760**, **760f**
- treatments for, **559**, **565**, **762**
- salvarsan first used to treat, **12**
- syphilis, rashes of, **753**, **754f**
- syringes, AIDS, hepatitis B transmitted by, **447**
- systematics (phylogeny), **273**
- systemic anaphylaxis (anaphylactic shock), **528**, **529**–**530**
- systemic infection (generalized infection), **409**
- systemic inflammatory response syndrome (SIRS), **646**
- systemic lupus erythematosus, **472b**, **537**
- systemic mycoses, **339**, **340t**
- T**
- T antigen, **393**
- T-cell receptors (TCRs), **480**
- T cells, **458**, **480**, **489**–**494**
- cellular immunity and, **480**, **486**–**489**
- classes of, **490**
- in compromised hosts, **416**
- cytotoxic, **490**, **493**, **493f**
- in delayed hypersensitivity reactions, **529**–**530**, **530f**, **531b**
- dendritic cells importance to, **490**
- diabetes mellitus and, **538**
- differentiation of, **489**, **489f**
- DiGeorge syndrome and, **541b**
- helper. *See* T helper cells
- in HIV/AIDS, **545**–**550**, **547f**, **548f**
- HIV (*Lentivirus*) and destruction of, **445t**. *See also* HIV
- leukemia viruses and, **393**
- lymph node location of, **458**, **645**, **645f**
- memory cells and, **489**
- regulatory, **492**–**493**, **500t**
- spleen and, **494b**
- superantigens stimulate proliferation of, **439**
- as third line of defense, **452f**
- thymus as maturation site, **459**, **459f**, **489**, **541b**
- T cytotoxic cells (T<sub>C</sub>), **490**, **493**, **493f**
- T-dependent antigen, **485**, **485f**
- T-DNA, **263**, **264f**
- T-even bacteriophages, **58f**, **376f**
- viral multiplication and, **381**–**383**, **382f**
- T helper cells (CD4<sup>+</sup> T cells), **490**–**492**, **491f**, **492f**
- follicular (T<sub>FH</sub>), **492**
- T<sub>H</sub>1 cells, **491**–**492**, **492f**, **496t**, **499b**
- T<sub>H</sub>2 cells, **491**–**492**, **492f**, **496t**
- T<sub>H</sub>17 cells, **491**–**492**, **492f**
- T helper cells (T<sub>H</sub>), **490**–**492**, **491f**
- in antibody production, **485**, **485f**
- T-independent antigens, **485**, **487b**, **487f**, **503**
- T lymphocytes. *See* T cells
- T regulatory cells, **492**–**493**, **496t**
- T suppressor cells. *See* T regulatory cells
- table sugar (sucrose), **38**, **38f**
- tachycardia, as complication of fever, **466**
- tachyzoites, **352**
- in toxoplasmosis, **661**, **662f**
- Tacrolimus (FK506), **542**
- Taenia saginata*, **358**–**359**, **364t**
- Taenia solium*, **359**, **364t**, **413t**
- Taeniasis, **739**
- tail, of T-even bacteriophage, **376f**, **382f**
- tail fiber, of T-even bacteriophage, **376f**, **382f**
- Talaromyces*, **338f**
- Tamiflu (oseltamivir), **566t**, **575**, **701**
- Tamm, Sid, **106b**
- tap water, *Acanthamoeba* grows in, **351**
- tapeworms (cestodes), **358**–**360**, **360f**, **361f**, **364t**, **738**–**739**, **738f**, **740b**
- beef (*Taenia saginata*), **358**, **359**, **364t**, **739**
- Echinococcus granulosus* and, **359**–**360**, **361f**, **364t**
- foodborne transmission of, **413t**
- niclosamide to treat, **562t**, **577**
- pork (*Taenia solium*), **359**, **364t**, **413t**, **739**
- Taq polymerase enzyme, **326**, **767**
- TASS (toxic anterior segment syndrome), **436b**
- Tatum, Edward L., **10f**, **13t**, **15**
- taxa/taxon, **273**
- taxis, **82**
- Taxol
- genetically modified, ovarian cancer therapy, **259t**
  - produced by *Taxomyces*, **341**
  - yew trees and, **341**
- Taxomyces*, **341**
- taxonomic hierarchy of organisms, **278**, **279f**
- taxonomy, **272**, **273**
- advances in, **263**
  - of microbes, **272**–**298**. *See also* classification
  - as tool for natural classification system, **275**
  - of viruses, **374**–**375**, **377**–**378t**
- tazarotene (Tazorac), **599**
- Tazorac (tazarotene), **599**
- TB. *See* tuberculosis
- TCRs (T-cell receptors), **480**
- TDP (thermal death point), **185**
- TDT (thermal death time), **185**
- tears
- IgA antibodies in, **480**
  - lysozyme in, **88**, **455**
  - as protective mechanism, **452f**, **454**, **474t**
- teeth, biofilm formation as plaque, **161**
- “teflon pathogen” *Treponema pallidum*, **754**
- teichoic acids, **84**, **85f**, **86**, **87t**
- teleomorphs, **338**
- telithromycin (Ketek), **565t**, **571**
- telomeres, **260**
- TEM (transmission electron microscope), **62**–**63**, **63f**, **66t**
- Paramecium* micrograph, **63f**, **66t**
- specimen preparation and, **62**–**63**
- specimen size and, **58f**
- T-even bacteriophages (viruses) micrograph, **58f**
- Temin, Howard, **10f**
- temperate phages (lysogenic phages), **383**–**384**, **383f**
- temperature
- agar and, **162**
  - autoclaves and, **185**–**187**, **186f**, **186t**, **191t**, **441**, **442t**
  - disinfectants' effectiveness and, **186**
  - enzymes and, **113**, **116**–**117**, **117f**
  - extremes, archaea and, **4**, **274**, **274f**
  - food preservation and, **155**–**156**, **155f**, **156f**
  - freezing, bacterial growth and, **189**
  - highest on record for bacterial growth, **156**
  - low, to control microbial growth, **188**–**189**
  - microbial growth requirements and, **154**–**156**, **154f**–**156f**
  - optimum for pathogenic bacteria, **117**, **155**
  - pasteurization and, **187**–**188**
  - steam heat and, **185**–**187**, **186t**, **191t**
  - thermal death point and, **185**
  - thermal death time and, **185**
  - water as buffer for, **34**
- temperature abuse, food poisoning and, **717**
- template strand of DNA, **214f**, **215**
- tenofovir, **553**, **575**
- teratogenic drugs, **600**
- terbinafine, **566t**, **574**, **606**
- terminator (DNA strand site), **214f**, **215**
- terminology
- of microbial control, **182**, **183t**
  - scientific nomenclature, **2**–**3**, **4t**, **278**, **279f**
- termites
- as example of endosymbiosis, **106b**
  - Paecilomyces fumosoroseus* fungus as biocontrol, **341**
  - spirochetes bacteria and, **325**
- Terramycin (oxytetracycline), **565t**, **570**
- terrorism, biological weapons and, **190**, **261**, **654b**
- tertiary sewage treatment, **794**
- tertiary structure of proteins, **44**, **45f**
- test tubes, culture media and, **162**
- testes, **750**, **750f**
- tests for water purity, **785**–**787**
- tetanospasmin. *See* tetanus toxin
- tetanus, **96**, **159**, **441t**, **442t**, **621**–**622**, **621f**, **638b**
- from bacteria in soil, **409**
  - caused by *Clostridium tetani*, **314**, **441t**, **621**, **638b**
  - incubation period, **431t**
  - as notifiable infectious disease, **424t**
  - portals of entry, **430**, **431t**
  - symptoms of, **407**, **441t**, **621**
  - tetanospasmin toxin causing symptoms of, **439**, **441t**, **621**
  - vaccine, **14**, **506t**, **507t**, **621**
  - as a toxoid, **438**, **506t**, **507t**, **508**, **621**
  - antitoxins/antisera as, **508**, **522**
- tetanus immune globulin (TIG), **621**
- tetanus toxin (tetanospasmin), **439**, **441t**, **442t**, **621**
- produced by *Clostridium tetani*, **235**, **439**, **441t**, **621**
  - vaccine made from purified, **506t**, **508**, **621**
- tetherins, **553**
- tetracyclines, **561f**, **562t**, **565t**, **570**–**571**, **571f**
- inhibition of protein synthesis by, **9**, **561f**, **563**, **563f**, **565t**
  - produced by *Streptomyces aureofaciens*, **560t**
  - resistance genes to, **236**, **238f**
  - selective toxicity and, **565**
  - superinfections and, **571**

- susceptibility of gram-negative vs. gram-positive bacteria to, 87*t*  
 to treat *H. pylori* peptic ulcer disease, 71*b*  
 to treat inclusion conjunctivitis, 610  
 to treat tularemia, 649  
 tetrads, 77, 77*f*  
*Tetrahymena* (protozoan), cilia of, 99, 99*f*  
 tetrapeptide side chain, in bacterial cell walls, 84, 85*f*  
 Tetraviridae, 396*t*  
 tetroses, 39  
 textiles, microbes in manufacture of, 244  
 thallus (body), 332, 333  
   of algae, 343, 344  
   of lichen, 342, 343*f*  
 thawing, of freeze-thaw cycle, 189  
 therapeutic index, antibiotics and, 576  
 ThermaClear, to treat acne, 600  
 thermal cyclers, 157*b*, 249, 251  
 thermal death point (TDP), 185  
 thermal death time (TDT), 185  
*Thermoactinomyces vulgaris*,  
   regenerated 7500-year-old  
   endospores of, 96  
*Thermococcus litoralis*, 157*b*  
 thermophilic bacteria  
   acid-anionic sanitizers and, 196  
   pasteurization and, 187  
   thermophiles, 154, 155–156, 326. *See also* extreme thermophiles  
   thermophilic anaerobic spoilage, 800–801  
   thermophilic archaea, optimal growth temperatures, 156, 326  
   thermophilic bacteria  
     food spoilage and, 182, 795, 796*t*  
     *Thermus aquaticus* as, 251, 767  
   *Thermotoga*, 275, 280*f*  
   *Thermovibrio ammonificans*, 157*b*  
   *Thermus aquaticus*, 251, 326, 767  
   *Thermus* genus/spp., 302*t*  
   thiamine (vitamin B<sub>1</sub>), 115*t*, 158  
 thickening agents  
   agar, 346. *See also* agar  
   alginate, 345–346  
   carrageenan, 346  
*Thiobacillus ferrooxidans*, 143  
   pH ranges and, 35  
   used in copper ore recovery, 806  
*Thiobacillus* genus/spp., 300*t*, 306, 772  
   sulfur granules of, 95  
   as sulfur oxidizers, 143, 300*t*, 306, 772  
*Thiobacillus thiooxidans*, 143  
*Thiomargarita* genus/spp., 301*t*, 317  
*Thiomargarita namibiensis*, 14, 299*f*, 327, 327*f*  
 Thiotrichales, important genera of, 301*t*  
 30S ribosomes, 94, 94*f*  
 Thomas, E. Donnell, 13*t*  
 thoracic (left lymphatic) duct, 458, 459*f*  
 three-dimensional images  
   AFM microscope and, 65, 65*f*, 67*t*  
   confocal microscope and, 62, 62*f*  
   DIC microscope and, 59, 61*f*, 65*t*  
   SEM microscopes and, 63–64, 63*f*  
 three-domain system, 273–275,  
   274*f*, 276*t*  
   evolutionary relationships, 273–275,  
   274*f*, 276*t*  
 threonine (Thr)  
   *E. coli* and synthesis of, 119  
   structural formula/characteristic R group, 42*t*  
 throat, normal microbiota of, 404*t*  
 thrombocidin, produced by platelets, 473  
 thrombocytes. *See* blood platelets  
 thrombocytopenic purpura, 533, 534*f*  
 thrush (oral candidiasis), 341, 606, 607*f*, 759  
 thylakoids (chromatophores)  
   of bacteria, 90, 90*f*, 138, 143, 143*t*  
   of eukaryotic cells, 103, 104*f*, 143*t*  
 thymic aplasia (DiGeorge syndrome), 543, 544*t*  
 thymic selection, 489, 532  
 thymine dimers  
   nucleotide excision repair and, 227–228, 228*f*  
   unrepaired, skin cancers and, 231  
   UV light exposure and, 190, 227–228, 228*f*  
 thymine nucleotide, 46*f*  
 thymine (T), 46*f*, 47, 208  
   in DNA replication, 210–215,  
   211*f*–214*f*  
   exposure to UV light and, 227–228,  
   228*f*  
   in translation, 216–218, 216–217*f*  
 thymus, 459, 459*f*, 480, 531*b*  
   diabetes mellitus and, 538  
   DiGeorge syndrome and, 541*b*  
   T cells and, 459, 489, 490*f*. *See also* T cells  
 Ti plasmid, as vector for plant genetic modification, 263–264, 264*f*  
 ticarcillin, 568  
 tickborne diseases, 290, 304, 325, 362, 364*t*  
 ticks, 58*f*, 356*t*, 364*t*  
   as arthropods, 331*f*  
   cattle, 690  
   compound light microscope micrograph, 58*f*  
   *Dermacentor* species, 655, 656*f*  
   as disease reservoirs, 413*t*, 656*b*  
   *Ehrlichia* transmitted by, 304  
   ivermectin effective against, 572  
   *Ixodes* species, 352, 362*f*, 364*t*, 413*t*, 653  
   Lone Star, 654  
   *Ornithodoros* species, 364*t*  
   *Rickettsia* transmitted by, 304  
   as vectors, 364*t*, 413*t*  
 TIG (titanium immune globulin), 621  
 tigecycline (Tygacil), 565*t*, 571  
 time factors  
   antimicrobial agents and, 186, 195  
   ethylene oxide's antimicrobial action and, 198  
   resistant microbes and, 186  
 tincture of iodine, 193, 202*t*  
 tincture of Zephiran, 196*f*  
 tinctures, 193  
   effectiveness of, vs. aqueous solutions, 195, 196*f*  
 tineae capitis (ringworm), 605, 606*f*  
   griseofulvin to treat, 569  
 tineae cruris (jock itch), 605  
 tineae pedis (athlete's foot), 568, 605, 606*f*  
 tineae unguium (onychomycosis), 606  
   tinidazole, 566*t*, 577  
 tissue cells, relation to lymphatic capillaries, blood capillaries, 456*f*  
 tissue cysts, 661–663, 662*f*  
 tissue-destroying diseases  
   actinomycosis, 320  
   mycetoma, 320  
   necrotizing fasciitis, 19, 286, 317, 320, 423*b*, 595–596, 596*f*  
 tissue digester, to dispose of prion-infected animals, 631, 631*f*  
 tissue fluids, lysozyme in, 455  
 tissue plasminogen activator, 259*t*  
 tissue rejection  
   histocompatibility antigens and, 482  
   surgery-damaged cells and, 534  
 tissue repair, inflammatory response and, 464*f*, 465  
 tissue typing, 538, 538*f*  
 titer, 515–516, 516*f*  
 TLRs. *See* Toll-like receptors  
 TMD (tobacco mosaic disease). *See* tobacco mosaic virus  
 TMP-SMZ (trimethoprim-sulfamethoxazole), 565*t*, 573, 573*f*  
 TMV (tobacco mosaic virus), 14, 369, 370  
 Tn5 transposon, 238*f*  
 Tn1546 transposon, 237, 239  
 TNF. *See* tumor necrosis factor  
 tobacco mosaic virus (TMV), 14, 369, 370, 372*f*  
*Tobamovirus*, 396*t*  
 tobramycin, 570  
 toenails, cutaneous mycoses and, 340  
 Togaviridae, 377*t*, 388, 388*t*  
*Togavirus*/EEE virus (eastern equine encephalitis), 377*t*, 625, 628*b*  
*Togavirus*/WEE virus (western equine encephalitis), 377*t*, 625, 628*b*  
 Toll-like receptors (TLRs), 452, 460–462, 461*f*  
   in activation of T helper cells, 491  
   antimicrobial proteins (AMPs) and, 473  
   as early warning system in adaptive immunity, 481, 579  
   in inflammatory response, 463  
 tolnaftate, 566*t*, 575  
 toluene, bacteria that use as energy/carbon source, 235  
 tomatoes, salmonella outbreak, 715*b*  
 tomatoes (MacGregor variety), 266, 267*t*  
 Tonegawa, Susumu, 13*t*, 487  
 tongue, 681*f*  
   normal microbiota of, 17*f*  
 tonoplast, 103  
 tonsillectomies, bacterial endocarditis and, 647  
 tonsillitis, 682  
 tonsils, 459, 459*f*  
 tooth decay (dental caries), 713–715, 714*f*, 716*b*  
   *Streptococcus mutans* and, 135*b*, 137*b*, 317, 432, 713–714  
 tooth extractions, bacterial endocarditis and, 647  
 topoisomerase, 210, 211*t*, 214  
 TORCH panel of tests, 768  
 total magnification calculation, 55–56  
 toxemias, 409, 437, 588, 640  
 toxic anterior segment syndrome (TASS), 436*b*  
 toxic oxygen products, 159–160, 462  
 toxic shock syndrome (TSS), 441*t*, 594, 597*b*  
   exotoxins causing, 441*t*  
   gram-positive sepsis and, 650  
   lysogenic phages and, 384  
   as notifiable infectious disease, 424*t*  
   rash caused by, 597*b*  
   *Staphylococcus aureus* causing, 316, 441*t*, 594, 597*b*  
   toxic shock syndrome toxin 1 (TSST-1) strain, 594  
   streptococcal, 5, 14, 419*t*, 424*t*, 596  
   symptoms, 441*t*  
 toxic waste  
   bioremediation and, 16  
   microbes that minimize, 3*b*  
 toxigenicity, 436  
 toxins, 436–441, 447*f*  
   A-B toxins, 438–439, 438*f*, 441*t*, 442*t*  
   algae and, 345*t*, 346  
   amanitin, 445  
   antitoxins and, 438, 442*t*, 477  
   bacteriocins, 41, 235  
   cardiotoxins, 438  
   commercial sterilization and, 182, 183*t*, 794–795, 794*f*, 795*f*  
   of *Corynebacterium diphtheriae*, 235, 384  
   cytotoxins, 438  
   diatoms and, 345*t*, 346–347  
   dinoflagellates and, 345*t*, 346–347  
   domoic acid produced by diatoms, 346  
   early research with, 477  
   endotoxins, 437*f*, 439–441, 440*f*, 442*t*  
   enterotoxins, 438  
     of *E. coli*, 310  
   environmental, microbial ecology and, 15  
   ergot, 445  
   erythrogenic, 235, 677  
   exfoliative, 235  
   exotoxins, 437–439, 437*f*  
   fungal, 341, 445  
   gastric juice ineffective against, 455  
   hepatotoxins, 438  
   IgG antibodies and, 483*t*  
   intoxication by, vs. infection, 437  
   leukocidin, 423*b*  
   leukotoxins, 438  
   lysogenic phages and, 384  
   membrane-disrupting toxins, 438–439, 441*t*  
   neurotoxins, 235, 438, 439, 440, 445  
   phalloidin, 445  
   plasmids and, 95

- pore-forming, secreted by intracellular pathogens, 462
- potency and, **432**
- produced by gram-negative vs. gram-positive bacteria, **87t**
- prophage genes and, 384
- as proteins, 41
- R factor plasmids that confer resistance to, 235
- red algae and, **345t**, 346
- saxitoxins, **344**
- Shiga, 207, 235, 384
- streptococcal, 384
- trichothecenes, 445
- Toxocara canis*, 360, 364t
- Toxocara cati*, 360, 364t
- toxocariasis, 364t
- toxoids (inactivated toxins), **438**, 442t
- as vaccines, 438, **508**, 621
- Toxoplasma* genus/spp., pathogenic mechanisms of, 446
- Toxoplasma gondii*, 352, 356t
- causing encephalitis in AIDS patients, 550t
- interleukin-12 to treat, **499b**
- life cycle of, **669f**
- pregnancy dangers and, 352
- reservoirs/transmission method, 413t
- U.S. prevalence of antibodies against, 662, 663f
- toxoplasmosis, 356t, 413t, **655b**, **668**, 669f
- of brain, in AIDS patients, 542, 550t, 668
- California sea otter deaths and, **282b**, 668
- cats infected with, **668**, 669f
- disease reservoirs for, 413t
- pregnancy and, 760
- Toxoplasma gondii* causing, 356t, 668, 669f
- transmission due to, 413t
- U.S. prevalence of antibodies against, 663f
- TPM (two-photon microscopy), **60**, 62f, 66t
- Paramecium* micrograph, 62f, 66t
- trace elements, **158**
- activating enzymes and, 115
- microbial growth and, 158
- tracheotomy, compromised hosts and, 416
- trachoma, 322, 430, 462, **609b**, **610**, 610f
- blindness and, 322, 610
- trans fatty acid, 40
- transacetylase, 219, 221f
- transamination, **145**, 145f
- transcription, 210f, 214f, **215**, 218, 218f
- control mechanisms on, 219–221, 221f, 222f
- DNA viruses and, 386, 388t
- in eukaryotic cells, 218, 219f
- RNA viruses and, 388, 389f
- translation and, 215, 217–218, 218f.
- See also translation
- transduction (bacterial), **234–235**, 237f
- generalized, **234–235**, 237f, 384
- specialized, **235**, 237f, **384**, 384f
- transfer RNA (tRNA), **47**, 208, **216**
- in translation, 216–218, 216–217f, 218, 218f
- transfer vesicles, **102**, 104f
- transferase enzymes, 115t
- transferrin, 434, 466, **473**
- high body temperature and, 466
- transformation (genetic), **232–233**, 233f, 234f, **251**
- in continuous cell lines, 380
- as genetic engineering technique, 251
- naturally occurring, 236
- in tumor cells, 393, 542, 543f
- by viruses, 393, 443–444, 447f
- transfusion reactions, 528t, 532–533, 532t, 533f, 544t, 554b
- transgenic animals, 258, 259t, 267t
- transient microbiota, **402**
- translation, 210f, **215–218**, 216–217f, 218, 218f
- DNA viruses and, 386, 388t
- in eukaryotic cells, 218, 219f
- transcription and, 215, 217–218, 218f
- translational reading frame, frameshift mutations and, 225
- transmembrane proteins, 89f, 90
- transmissible spongiform encephalopathies (TSE), **636–637**, 636f, 637t, 638b
- transmission electron micrograph, defined, 62
- transmission electron microscope (TEM), **62–63**, 63f, 66t
- Paramecium* micrograph, 64f, 67t
- specimen preparation and, 62–63
- specimen size and, 58f
- T-even bacteriophages (viruses) micrograph, 58f
- transmission of disease
- biological transmission and, **414**
- by direct contact, **411**, 412f, 413t
- by droplets, **411–412**, 412f
- by flea bites, 413t, 414t
- by fomites, **411**, 412f, 413t, 416
- by indirect contact, **411–412**, 412f, 413t
- by ingestion, 413t
- mechanical transmission by arthropods and, 414
- by mosquito bites, 414t
- in nosocomial infections, 415f, 416, 416t, 417t
- by tick bites, 413t, 414t
- by vectors, **413–414**, 414t
- by vehicle (air/food/water), **412–413**, 412f
- transplacental transfer of immunoglobulins, 483t, 498
- transplant rejection
- cytotoxic T lymphocytes (CTLs) and, 493, 529
- delayed (Type IV) hypersensitivity reaction and, 528t, 535, 537b
- genetically modified products to minimize, 259t
- immunologically privileged sites/privileged tissue, 534–535
- impaired innate defenses and, 465
- mechanisms of, 534–535
- monoclonal antibodies to minimize, 514
- transplant surgery
- HLA tissue typing, 533–534, 533f
- immunosuppression and, 541–542
- using PCR in matching donors, 534
- transplantation reactions, 539–541, 540f
- Type IV delayed-hypersensitivity reactions and, 535
- transplants
- bone marrow, **536**
- corneal, 559b
- liver, 536
- transport media, **283**
- transport vesicle, **102**, 104f
- transporter proteins, 41
- in active transport processes, 93
- in facilitated diffusion, 91–92, 91f
- transposase, 211t, 237, 238f
- transposition, 237, 238f, 239
- frequency of, 237
- transposons, 235, 237
- antibiotic resistance and, 237, 238f, 239, 580
- complex, 237, 238f
- evolution and, 239, 275
- gene silencing and, 258
- human genome and, 260
- trastuzumab (Herceptin), 514, 543
- traveler's diarrhea, **441t**, **724**, 728b
- enterotoxigenic *E. coli* and, 235, 310, **724**, 728b
- exotoxins causing, 235, 310, 441t
- trees
- ascomycete *Cryphonectria parasitica* and chestnut trees, 341
- Ceratocystis ulmi* causing Dutch elm disease, 342
- chestnut, *Cryphonectria parasitica* and, 341
- oak, *Phytophthora ramorum* and, 348
- redwood, *Phytophthora ramorum* and, 348
- that produce anticancer therapies, 341
- Trematodes (flukes), **356–358**, 358f, 359f, 364t
- immune system attack on, 491, 492f
- praziquantel to treat, 562t, 577
- trench mouth (acute necrotizing ulcerative gingivitis), **716**, 716f
- Treponema* genus/spp., 302t, **325**, 325f
- as normal microbiota of mouth, 404t
- portals of entry, 430, 431t
- Treponema pallidum pertenuis*, 753
- Treponema pallidum*, **325**, 325f, 758–759, 759f
- adherence method of, 433, 752
- axial filaments of, 82, 83f, 325, 325f
- blood banks screen for, 727b
- cultivation of virulent strains and, 406
- darkfield microscopy to detect, 57, 66t
- FTA-ABS test micrograph, 61f, 65t
- mucous membranes (moist) and, 453–454
- portals of entry, 430, 431t
- syphilis caused by, 325, 325f. See also syphilis
- as “teflon pathogen”, 754
- yaws caused by subspecies strains, 753
- tretinoin, 599
- triangular-shaped bacteria, 78
- Triatoma* (kissing bug), 350, 356t, 363f, 364t, 413t
- triazole antifungal antibiotics, **574**, 661
- Tribonema vulgare* (algal cell), 98f
- tricarboxylic acid (TCA) cycle. See Krebs cycle
- trichiasis, 610, 610f
- Trichinella spiralis*, 364t, 705f
- life cycle of, 743, 743f
- portals of entry, 431t
- reservoirs/transmission method, 413t
- trichinellosis caused by, 740b, **743–744**
- trichinellosis, 361, 364t, 413t, 705f, **740b**, **743–744**, 743f
- disease reservoirs for, 413t
- freezing temperatures and, 189
- incubation period, 431t
- microwave ovens and, 190
- as notifiable infectious disease, 424t
- transmission due to, 413t
- Trichoderma*, 3b, 38, 341
- Trichodesmium*, 777–778
- Trichomonas vaginalis*, 349, 350f, 356t, 767f
- metronidazole to treat, 571
- as normal microbiota of vagina, 404t, 760
- vaginitis caused by, 347, 756, 759b
- trichomoniasis, **766**, **766b**, 768, 768f
- TORCH panel of tests and, **768**
- Trichonympha sphaerica*, 106b
- Trichophyton* (*Arthroderma*), 340t, 445
- cutaneous mycosis and, 597b, 605–606
- reservoirs/transmission method, 413t
- trichothecenes, 445
- Trichuris trichiura*, 361, 364t, 740b, 742, 742f
- trickling filters, in sewage treatment, **791**, 792f
- triclosan, 192–193, 193f, 201t
- Tridacna* (giant clam), 348
- trigeminal nerve ganglia, herpes simplex virus and, 597–598, 598f
- triglycerides (fats), 39–40, 39f, 135
- trimethoprim, 565t, 573, 573f
- trimethoprim-sulfamethoxazole (TMP-SMZ), 565t, **573**, 573f
- trioses, 39
- tripeptide, 43
- triple reassortment H1N2, 377b
- tRNA, of Archaea/Bacteria/Eukarya compared, 276t
- tRNA. See transfer RNA
- Tropheryma whipplei*, 290
- trophophase, **803**, 804f



- trophozoites, **348**  
 of *Balantidium coli*, 353  
 of *Giardia*, 350f  
 of *Toxoplasma gondii* and, 352  
 true flies, as vectors of human diseases, 364t  
 truffles, 773–774, 774f  
 Truvada, 553  
*Trypanosoma*, 350  
 antigenic variation used by, 435, 446, 629, 629f  
 regulation of gene expression and, 219  
*Trypanosoma brucei gambiense*, 350, 356t, 414t  
 antigenic variation in, 435, 446, 629, 629f  
 trypanosomiasis caused by. *See* trypanosomiasis  
 tsetse fly as vector, 350, 356t, 364t, 414t, 633  
*Trypanosoma brucei rhodesiense*, 356t, 414t, 633  
*Trypanosoma cruzi*, 4t, 330, 350, 356t, 414t, 419t, 462, 656b, 666–667, 667f  
 blood banks screen for, 727b  
 Chagas' disease caused by, 656b, 666–667  
 trypanosomes  
 antigenic variation in, 435, 446, 633, 635f  
 in Chagas' disease, 350, 661, 661f  
 evasion of immune system by, 633, 635f  
 schizogony and, 350  
 trypanosomiasis  
 African, 219, 330, 350, 356t, 363, 364t, 413t, 435, 446, **633**, **638b**  
 American. *See* Chagas' disease  
 tryptophan (trp)  
 in indigo production, 3f  
 structural formula/characteristic R group, 42t  
 synthesis repression, 221, 222f  
 TSE (transmissible spongiform encephalopathies), **636**–637, 636f, 637t, 638b  
 tsetse fly, as vector for African trypanosomiasis, 356t, 364t, 413t, 446, 633, 638b  
 TSS. *See* toxic shock syndrome  
 TSTA (tumor-specific transplantation antigen), **393**  
 tuberculin skin test, 512, 530, **690**, 690f  
 tuberculocidal agents  
 instruction labels and, 202  
 tests for effectiveness, 203  
 tuberculoid (neural) form of leprosy, 619, 620f  
 tuberculosis (TB), **688**–692, 688f, **706b**  
 acid-fast stain to identify, 70  
 in AIDS patients, 549, 550f  
 airborne transmission and, 413  
 antibiotics to treat, 569, 570, 572, 684, 690–691  
 biochemical tests to detect, 142b  
 bovine (*Mycobacterium bovis*), **688**  
 cases reported 1948–2010, 424f  
 causative agent of, 142b, 319, 682f. *See also* *Mycobacterium tuberculosis*  
 as chronic disease, 409  
 chronic inflammation of, 460  
 desiccation resistance by bacterium causing, 189  
 diagnosis of, 690, 690f  
 extensively drug-resistant (XDR) strains of, **691**  
 fluorescent dyes to identify, 61  
 incidence of, worldwide, 691, 692f  
 incubation period, 431t  
 multidrug-resistant (MDR-TB) strains and, 18, **691**  
 as notifiable infectious disease, 424t  
 pathogenesis, 682–684, 683f  
 peritoneal, 142b  
 portal of exit, 446  
 portals of entry, 430, 431t  
 pulmonary, 142b  
 reported cases, 1948–2007, 424f  
 skin test, 512, 530, **690**, 690f  
 susceptibility testing and, 691  
 treatments of, 690–691  
 vaccine, 14, 509, **691**  
 worldwide incidence, 685, 686f  
 tubulin, 99  
 tularemia, 364t, 447, **647**–649, 650f, **656b**  
*Chrysops* (deer fly) as vector transmitting, 364t  
*Francisella tularensis* causing, 307, 462, 648, 656b  
 hamsters (Clinical Focus) case study, **656b**  
 as notifiable infectious disease, 424t  
 number of cases in U.S. (1990–2000), 642, 642f  
 as potential biological weapon, 642, 654b  
 as zoonotic disease, 648  
 tumor cells  
 natural killer (NK) cells can destroy, 495  
 transformation and, **393**, 542, 543f  
 tumor-destroying (oncolytic) viruses, 371  
 tumor necrosis factor alpha (TNF- $\alpha$ ), **440**, 440f  
 disorders leading from excessive production of, 463  
 in fever, 466  
 in inflammatory response, 463  
 psoriasis and, 538  
 tumor necrosis factor (TNF),  
 rheumatoid arthritis and, 512  
 tumor necrosis factor (TNF), **496**–497  
 as cytokines, 496–497  
 endotoxic shock and, 440, 440f  
 genetically modified, 259t  
 tumor-specific transplantation antigen (TSTA), **393**  
 tumors  
 interleukin-12 (IL-12) and, 499b  
 mammary gland (mice), 392  
*Mastadenovirus* and, 377t  
*Papillomavirus* and, 377t, 387  
 reverse transcriptase, proviruses and, 391f, 393–394  
 transformation in, **393**  
 tungsten  
 used in staining of specimens, 63  
 used with gene guns, 252, 252f  
 turbidity, measuring, to estimate bacterial growth, 175, 176f  
 turkey farming, animal feed antibiotics and, 583b  
 turnover number of enzymes, **114**  
 12D treatment (*botulinal cook*), in commercial sterilization, **800**  
 twitching motility, **83**  
 two-kingdom classification system, 273  
 two-photon microscopy (TPM), **60**, 62f, 66t  
*Paramecium* micrograph, 62f, 66t  
 2-aminofluorene (2-AF), 232b  
 2-aminopurine, 226–227, 227f  
 Tygacil (tygecycline), 565t, 571  
 tygecycline (Tygacil), 571  
 Type I hypersensitivity, **528**–531, 528t  
 Type II hypersensitivity, 528t, **532**–534  
 Type III hypersensitivity, 528t, **534**–535  
 Type IV hypersensitivity, 528t, **535**  
 typhoid fever, 311, 430, **720**–772, 720f, 728b  
 culture medium and, 165  
 endotoxin causing, 442t  
 incidence of, 720, 720f  
 incubation period, 431t  
 infection still spread in convalescence, 410  
 as notifiable infectious disease, 424t  
 portal of exit, 446  
 portals of entry, 430–431, 431t  
*Salmonella typhi* as cause of, 311, 431t  
 transmitted by contaminated water, 411  
 urine as portal of exit, 447  
 vaccine, 508, 722  
 Typhoid Mary, 411, 721  
 typhoidal salmonellae, 719–720  
 typhus, 462, **656b**, **660**–662  
 causative agent/arthropod vector, 413t  
 endemic murine, 310, 364t, **656b**, **660**  
 caused by *R. typhi*, 304, 413t  
 disease reservoir/transmission due to, 413t  
*Xenopsylla* (rat flea) as vector, 364t, 414t  
 epidemic, 364t, **656b**, **660**  
 Nightingale's epidemiologic analysis of, 420  
*Pediculus humanus corporis* (body louse) as vector, 304, 363f, 364t, 414t, 660  
*Rickettsia prowazekii* and, 304, 413t, 414t, 660  
 tickborne, **661**. *See also* Rocky Mountain spotted fever vaccine, 660  
 typical pneumonia, 692  
 tyrosine (tyr), 41, 41f  
 structural formula/characteristic R group, 42t
- U**  
 ubiquinones (coenzyme Q), **127**, 127f  
 UDP-N-acetylglucosamine (UDPNAc), 144, 144f  
 UDPG (uridine diphosphoglucose), 144, 144f  
 UDPNac (UDP-N-acetylglucosamine), 144, 144f  
 UHT (ultra-high-temperature) treatments, **187**–188  
 ulcers  
 genetically modified epidermal growth factor to heal, 259t  
*Helicobacter pylori* and, 455  
 ultra-high-temperature (UHT) pasteurization, **187**–188  
 ultra-high-temperature (UHT) treatments, **187**–188  
 ultrasonic baths, test for endotoxins, 442b, 444b  
 ultraviolet (UV) light  
 to control microbes, 190, 190f  
 in microscopy, 59, 61f, 65t  
 mutagenic, 227–228, 228f  
 viral multiplication and, 384  
*Ulva* (green alga), 345f  
 umbilical cord blood, stem cells harvested from, 540, 541  
 uncoating in viral multiplication, **385**–386, 385t, 387f, 389f  
 undecylenic acid, antifungal activity of, 575  
 undulant fever. *See* brucellosis  
 undulating membrane, of *Trichomonas vaginalis*, **349**, 350f  
 universal ancestors, 274f, 275, 277  
 Universal Precautions for Health Care Personnel (CDC), 546t, 551  
 unsaturated fatty acids, 39, 39f, 40, 40f  
 uracil (U), 47, 47f  
 in translation, 216–218, 216–217f  
 uranium, 35  
 used in staining of specimens, 63  
*Ureaplasma* genus/spp., 301t, **318**  
*Ureaplasma urealyticum*, 758  
 urease test, 142b, 144f  
 ureidopenicillin, 568  
 ureteritis, 746  
 ureters, 750, 750f  
 urethra, 750, 750f  
 urethritis, 356t, 752, 755  
*Chlamydia trachomatis* causing, 322, 431t, **757**–758, **767b**  
 nongonococcal/nonspecific, 322, 431t, 462, **757**–758, **767b**  
*Trichomonas vaginalis* causing, 356t  
 uridine diphosphoglucose (UDPG), 144, 144f  
 uridine triphosphate (UTP), 144, 144f  
 urinary bladder, 750, 750f  
 urinary catheters  
 nosocomial infections and, 416, 417t  
 number of MRSA-infected patients related to, 423b  
 urinary system, **750**–754, 750f  
 bacterial diseases of, 752–753, 753b  
 normal microbiota of, 404t, 751  
 structure/function of, 750, 750f, 751f  
 urinary tract infections (UTIs), 402b, 752

- E. coli* causing, 310  
 as emerging infectious disease, 419*t*  
 endotoxin causing, 442*t*  
*Enterobacter* and, 312  
*Enterococcus faecalis* and, 317  
*Enterococcus faecium* and, 317  
 fluoroquinolones to treat, 567  
 nosocomial, 416*t*, 417*t*, 752  
*Proteus* causing, 311  
*Pseudomonas* and, 308  
 sulfa drugs to treat, 567  
 tetracyclines to treat, 565  
*Trichomonas vaginalis* causing, 349, 350*f*  
*Ureaplasma* and, 318  
 vancomycin-resistant enterococci and, 419*t*
- urine, 455  
 lysozyme in, antimicrobial activity and, 453, 474*t*  
 normal microbiota of urinary tract and, 745  
 pH of, 453  
 as portal of exit, 447  
 urinary catheters altering flow, infections and, 455  
 washes microbes from urethra, 455, 474*t*
- U.S. Geological Survey research, nanotechnology and, 264  
 U.S. Postal Service, anthrax bioterrorism and, 646, 654*b*  
 U.S. Public Health Service, 420  
 USA100 MRSA strain, 423*b*  
 USA300 MRSA strain, 423*b*  
 use-dilution test, 192  
*Usnea*, 342  
 usnic acid, from *Usnea* lichen, 342  
 uterine (fallopian) tubes, 477*f*, 750, 751*f*  
 infection (salpingitis), 752  
 uterus, 750, 751*f*  
 UTP (uridine triphosphate), 144, 144*f*  
 UV light. *See* ultraviolet (UV) light
- V**  
 V factor, *Haemophilus* bacteria and, 312  
 V-P (Voges-Proskauer) test, 282*b*, 285*f*, 286  
 Vancomycin, to treat meningitis, 619  
 vaccination (immunization), 11, 479, 498, 505–511  
 antigenic variation and, 509, 511  
 artificially acquired active immunity and, 498  
 booster, 418, 506*t*, 507, 508, 616  
 childhood, recommended schedule for, 507*t*  
 Clinical Case, 505*b*, 508*b*, 511*b*, 514*b*, 519*b*, 522*b*  
 development of new vaccines, 509, 511  
 emerging infectious diseases and, 418  
 herd immunity and, 409, 505, 598, 612  
 how it works, 409, 498, 505  
 Jenner's research and, 11, 505  
 rates of, 409  
 vaccines, 14, 498, 504–511, 505
- adjuvants and, 511  
 against bacterial diseases, 506*t*  
 against viral diseases, 506*t*  
 attenuated (live), 507  
 boosters, 418, 506*t*, 507, 508, 616  
 cancer, 543  
 childhood, 507*t*, 621  
 conjugated, 508  
 development of new, 509, 511  
 DNA, 258, 508  
 filtration used to sterilize, 188, 191*t*  
 first, 11  
 gene guns to inject, 508  
 inactivated killed, 507–508  
 injection sites, dendritic cells and, 494  
 killed, 507–508  
 live attenuated, 507  
 microbes used in commercial production of, 245, 259*t*  
 nucleic acid (DNA vaccines), 508  
 oral, 509  
 patches (skin) as, 509  
 primary immune response provoked by, 505  
 as rDNA product, 258, 259*t*  
 recombinant, 508  
 recommendations for, 506*t*, 507*t*  
 safety of, 266, 511  
 secondary immune response and, 505  
 sources for recommended immunizations, 506  
 subunit, 259, 508  
 toxoids (inactivated toxins) as, 438, 508, 616  
 for travelers, 505–506  
 types of, 11, 507–508  
 UV light to disinfect, 190  
 viral, animal cells used to produce, 244  
 yeast genetically modified to produce, 245, 258, 259*t*
- vaccinia virus, 377*t*  
 confers immunity to smallpox, 505  
 genetically modified, 257  
 size of, 371, 372*f*  
 vaccine, 505  
 vacuoles, 98*f*, 103  
 food, 346, 349, 350*f*, 351*f*  
 gas, 95  
 of protozoa, 349  
 vagina, 750, 751*f*  
*Haemophilus* and, 312  
 normal microbiota of, 312, 326, 404*t*, 745  
 pH of, 745  
 vaginal infections. *See* vaginitis  
 vaginal secretions  
 as defense against pathogens, 455, 474*t*  
 pH of, 455  
 vaginal yeast infections, miconazole to treat, 568, 569*f*  
 vaginitis, 319, 356*t*, 762–763, 762*f*, 766*b*  
*Candida albicans* and, 403, 606, 756, 762–763, 766*b*  
*Gardnerella vaginalis* and, 312, 762–763, 766*b*
- Trichomonas vaginalis* and, 349, 356*t*, 571, 762, 766*b*  
 vaginosis, bacterial, 756, 756*f*, 759*b*  
 valacyclovir, 602  
 valence, 27, 28*t*  
 of antibodies, 479  
 valine (Val), structural formula/characteristic R group, 42*t*  
 Valley fever. *See* coccidioidomycosis  
 van Leeuwenhoek, Anton, 7, 7*f*, 10*f*, 13, 53, 54, 55, 325  
 vancomycin, 20*b*, 423*b*, 561*f*, 564*t*, 569  
 MRSA problem and its importance to, 569  
 resistance  
 antibiotics developed in response to, 566  
 by *S. aureus* (VISA), 18, 419*t*, 423*b*, 424*t*  
 by *S. aureus* (VRSA), 12, 18, 207, 237, 419*t*, 423*b*, 424*t*, 569  
 transposons and, 223*t*, 239  
 vancomycin-intermediate  
*Staphylococcus aureus* (VISA), 18, 423*b*  
 as nationally notifiable infectious disease, 424*t*  
 vancomycin-resistant enterococci (VRE), 419*t*, 569, 583*b*, 647  
 vancomycin-resistant *Staphylococcus aureus* (VRSA), 12, 18, 207, 237, 419*t*, 423*b*, 563  
 as nationally notifiable infectious disease, 424*t*  
 variable (V) regions, of antibodies, 482, 482*f*, 487  
 varicella (chickenpox), 377*t*, 387, 394, 596–597, 597*f*  
 breakthrough varicella, 597  
 incubation period, 431*t*, 596  
 as notifiable infectious disease, 424*t*  
 portals of entry, 431*t*, 596  
 rash caused by, 394, 596*b*  
 Reye syndrome complication of, 596  
 vaccine, 14, 506*t*, 507*t*, 596–597  
 varicella-zoster virus (*Varicellovirus*/HHV-3), 377*t*, 596–597. *See also* chickenpox  
 AIDS-associated, 550*t*  
 causing shingles, 377*t*, 596–597. *See also* shingles  
 incubation period, 431*t*  
 portals of entry, 431*t*  
 pregnancy and, 760  
 vaccine, 14, 506*t*, 507*t*, 596–597  
*Varicellovirus* (chickenpox virus), 394, 396*t*  
*Varicellovirus*/HHV-3. *See* varicella-zoster virus  
 variola major, 595  
 variola minor, 595  
 variola virus, 376*f*  
 variolation, 505  
 Varmus, Harold E., 13*t*, 393  
 vasodilation in inflammatory response, 464, 464*f*  
 VDRL test, for syphilis, 761  
 vectorborne diseases, by arthropod vector/disease, 364*t*  
 vectors, 248, 363, 365, 413–414
- arthropods as, 363, 363*f*, 364*f*, 365, 413–414, 413*t*, 414*t*  
 biological transmission by, 414  
 DNA molecules as, 248–249, 249*f*  
 insects as, 413–414  
 mechanical transmission by, 414, 414*f*  
 shuttle, 251  
 viral DNA as, 251  
 vegetables and fruits, PAA for washing/disinfecting, 202  
 vegetative bacteria  
 desiccation and, 189  
 endospore-forming, 96–97, 96*f*, 332  
 freezing temperatures and, 188–189  
 high pressure to control, 189  
 vegetative cells  
 of myxobacteria, 313, 313*f*  
 resistance to desiccation and, 189  
 temperatures that kill, 97  
 vegetative hyphae, 332, 333, 333*f*, 347*f*, 348  
 vegetative pathogens  
 boiling water/flowing steam to kill, 185–188, 186*f*, 186*t*, 191*t*  
 disinfection to control, 182, 183*t*  
 microwave ovens and, 190  
 non-endospore-forming, disinfection to control, 182, 183*t*  
 vegetative structures  
 of algae, 343–344, 344*f*  
 of fungi, 332–335, 332*f*, 333*f*  
 of protozoa, 349  
 vehicle transmission of disease agents, 412–413, 412*f*  
*Veillonella* genus/spp., as normal microbiota of mouth, 404*t*  
 veins, parasitic helminths and, 364*t*  
 Venezuelan hemorrhagic fever, 378*t*, 419*t*  
 as emerging infectious disease, 419*t*  
 Venezuelan hemorrhagic virus, 18, 419*t*  
 ventilation systems, hospital, nosocomial infections and, 416  
 ventilator-related procedures, MRSA-infected patients and, 423*b*  
 vents, deep-sea hydrothermal, 156, 157*b*  
 vertebrates, as eukarya, 6  
 vertical gene transfers, 232  
 vesicles, 773, 774*f*  
 of endoplasmic reticulum, 102–103, 104*f*  
 vesicles (lesions), 591, 592*f*  
 vesicular-arbuscular mycorrhizae (endomycorrhizae), 773, 774*f*  
 vesicular stomatitis virus (VSV), 378*t*, 380*f*, 390*f*  
*Vesiculovirus*, 378*t*  
 veterinary microbiology  
 fungal infection (Clinical Case), 332*b*, 339*b*, 341*b*, 342*b*  
 marine mammal deaths, 282*b*  
 vaccines, 259*t*  
 West Nile virus, 220*b*, 220*f*, 503, 631, 634*b*  
*Vibrio cholerae*, 76, 310, 310*f*

- A-B enterotoxin (cholera toxin)  
 produced by, 438, 439  
 coevolution and, 429  
 incubation period, 431*t*  
 lysogenic phages and, 442  
 noncholera vibrios, 723, 728*b*  
 portals of entry, 430, 431*t*  
 as potential biological weapon, 654*b*  
*Vibrio cholerae*0:139, 722  
 Clinical Case, 773*b*, 784*b*, 787*b*,  
 792*b*, 793*b*, 795*b*  
 emerging infectious diseases  
 and, 419*t*  
 new serovar and evolutionary  
 changes, 18, 418, 419*t*  
 terminology used in naming,  
 311*footnote*  
 virulence and, 432  
*Vibrio* enterotoxin (cholera toxin),  
 439  
 produced by *Vibrio cholerae*,  
 438, 439  
*Vibrio* genus/spp., 78, 78*f*, 301*t*,  
 310, 310*f*  
 found in dolphins, 282*b*  
*Vibrio parahaemolyticus*, 310, 723  
*Vibrio vulnificus*, 723, 728*b*  
 Vibrionales, 301*t*, 309–310  
 vibrios, 78, 78*f*, 310  
 vibriosis, as notifiable infectious  
 disease, 424*t*  
 Vincent's disease (trench mouth),  
 716, 716*f*  
 vinegar  
 fermentation and, 134*t*  
 microbes used in production of, 800  
 viral agents, first used to produce  
 immunity, 11  
 viral diseases  
 of cardiovascular system, 662–666  
 development of drugs to treat  
 and, 12  
 of digestive system, 727–735  
 of eyes, 605, 609*b*  
 interferons' discovery and, 14  
 of lymphatic system, 662–666  
 of nervous system, 620–626  
 of reproductive system,  
 757–758, 761*b*  
 of respiratory system  
 lower, 697–702  
 upper, 685–686  
 of skin, 600–605  
 rashes caused by, 594*b*, 596*b*, 597*b*  
 viral DNA, as a vector, 251  
 viral gastroenteritis, 734–735, 734*f*  
 viral genome, 245  
 viral genomes, 261  
 directing biosynthesis inside host  
 cell and, 281  
 viral hemagglutination, 517, 517*f*  
 viral hemagglutination inhibition test,  
 517, 518*f*  
 viral hemorrhagic fevers, 665, 667*b*  
 emerging, 659–660, 667*b*  
 as nationally notifiable infectious  
 disease, 424*t*  
 viral infections  
 attachment sites and drug  
 development, 385  
 chronic, 394, 394*f*, 396*t*  
 gene silencing and, 258  
 latent, 394, 394*f*, 396*t*  
 modified into crop plants, 264  
 persistent, 394, 394*f*, 396*t*  
 viral meningitis, 617–618  
 enteroviruses often causing,  
 377–378*t*  
 viral multiplication, 381–392, 385*t*  
 in animal viruses, 385–392. *See also*  
 animal viruses  
 in bacteriophages, 381–385  
 compared, 385*t*  
 drugs that interfere with, 370  
 host range and, 370  
 stages of, 381, 382*f*, 383–385,  
 385*t*, 387*f*  
 viral pneumonia, 698  
 viral protein, DNA vaccines and, 258  
 viral proteins, produced by *S.*  
*cerevisiae*, 259*t*  
 viral RNA, reverse-transcription PCR  
 and, 251  
 viral RNA testing, 551  
 viral species, 281, 377  
 three-domain system and, 281  
 viral therapy, safety of, 371  
 viral vaccine preparations, egg proteins  
 and allergies to, 379  
 viral zoonoses, 413*t*  
 Virchow, Rudolf, 8  
 viremia, 409  
 poliovirus causing, 621  
*viridans streptococci*, 319  
 virions, 371. *See also* viruses  
 latent, 547, 547*f*  
 viral multiplication and, 381, 383*f*  
 viroids, 396–397, 397*f*  
 causing plant diseases, 396–397, 397*f*  
 introns and, 397  
 size of, 372*f*  
 virology, 14  
 viroosomes, 506  
 virstatin, 579  
 virucides, 182, 196  
 virulence, 70, 429  
 of algae, 446  
 antigenic variation and, 435  
 cell wall components and, 433  
 early experiments in, 11  
 enzymes' role in, 433–435  
 fungal, 445  
 genetic transformation and,  
 232–233, 233*f*  
 glycocalyx, capsules, biofilm role in,  
 80, 432–433  
 of helminths, 446  
 host cell cytoskeleton and, 435, 435*f*  
 ID<sub>50</sub> and, 432  
 LD<sub>50</sub>[A]50[a][u] and, 432  
 lysogeny and, 441–442  
 M protein and streptococci, 317, 433  
 plasmid genes encoding for,  
 441–442  
 of protozoa, 445–446  
 of viruses, 443–444, 444*f*, 445*t*  
 virus-host interactions, phage therapy  
 research and, 371, 579  
 viruses, 5, 5*f*, 75, 369–400, 370  
 as acellular microbes, 5  
 advantages of electron microscopes  
 to view, 61, 64  
 alcohol-based disinfectants and,  
 194–195, 202*t*  
 animal. *See* animal viruses  
 antigenic changes induced by, 442  
 antimicrobial drugs that inhibit,  
 370, 562*t*, 566*t*, 575–577, 576*f*.  
*See also* antiviral drugs  
 bacteria compared to, 370, 370*t*  
 bacterial. *See* bacteriophages  
 biocidal resistance and, 200, 203*f*  
 boiling water/flowing steam to kill,  
 185–187, 186*f*, 191*t*  
 cancer and, 392–394  
 DNA oncogenic viruses, 393  
 RNA oncogenic viruses, 393–394  
 transformation and, 393  
 capsid of, 371, 372*f*, 373*f*  
 capsomeres of, 371, 372*f*, 373*f*  
 cell cultures, 379–380, 380*f*  
 characteristics of, 370–374,  
 370*t*, 372*f*  
 chromosomal changes induced  
 by, 442  
 classification of, 281, 371, 394*b*  
 Clinical Case, 370*b*, 390*b*, 392*b*,  
 393*b*, 394*b*  
 cultivation of, 376, 379–380,  
 379*f*, 380*f*  
 bacteriophages and, 376, 376*f*, 379  
 cytopathic effects of, 443–444, 444*f*,  
 445*t*, 447*f*  
 desiccation resistance and, 189  
 disinfectants effective against, 193,  
 194, 196  
 distinguishing features, 370, 370*t*  
 early descriptions of, 369, 370  
 as emerging infectious diseases  
 (EIDs), 18, 419*t*  
 enveloped, 371, 373*f*  
 alcohol-based disinfectants and,  
 194, 202*t*  
 biguanide disinfectants and, 193  
 biocidal resistance and, 203, 203*f*  
 budding, 392, 392*f*  
 double-stranded DNA, 377*t*, 388*f*  
 double-stranded RNA, 378*t*  
 helical, 373, 373*f*  
 polyhedral, 372*f*, 373, 388*f*  
 quats active against, 196,  
 199*b*, 202*t*  
 single-stranded RNA, 377*t*,  
 378*t*, 388*f*  
 evolution of, 281  
 filterable, 188, 369, 370  
 in foodstuffs, radiation doses needed  
 to kill, 797*t*  
 gene silencing as defense against, 258  
 genetic information of, 261, 393, 394*b*  
 genetically modified to infect tumor  
 cells, 371  
 helical, 373, 373*f*  
 host range and, 370–371  
 host-virus interactions, phage  
 therapy and, 371, 579  
 identification of, 379, 380  
 IgG antibodies and, 483*t*  
 interferons to counter, 471–473,  
 471*f*, 474*t*  
 isolation of, 376, 379, 379*f*  
 latent, 384, 394, 394*f*, 396*t*  
 with lipid envelopes, resistance to  
 chemical biocides, 203, 203*f*  
 mammalian cell cultures as hosts  
 for, 256–257, 380*f*  
 mechanisms for evading host  
 defenses, 443–444, 444*f*, 445*t*  
 molecular methods of  
 identifying, 379  
 morphology of, 372*f*, 373–374, 373*f*  
 multiplication in, 381–392. *See also*  
 viral multiplication  
 natural killer (NK) cells can  
 destroy, 495  
 negative staining of, 63, 388*f*  
 nonenveloped, 371, 372*f*, 373,  
 377*t*, 378*t*  
 alcohol-based disinfectants and,  
 195, 202*t*  
 biocidal resistance and, 197*b*,  
 200, 200*f*  
 norovirus outbreak, 182*b*, 197*b*,  
 199*b*, 201*b*  
 single-stranded RNA, 377*t*, 378*t*  
 as obligatory intracellular  
 parasites, 370  
 Old World, introduced into New  
 World viruses, 220*b*  
 oncogenic (oncoviruses), 378*t*,  
 392–394  
 oncolytic, 371  
 origins of, 281  
 orphan, 390  
 pathogenic properties of, 443–444,  
 444*f*, 445*t*  
 peracetic acid effective against, 202  
 plant, 395–396, 396*t*  
 plaques and, 376, 376*f*, 395  
 reproduction of, 5, 12  
 resistance to chemical biocides,  
 200, 200*f*  
 rickettsias/chlamydias compared to,  
 370, 370*t*  
 size of, 5, 371, 372*f*  
 spikes of, 371, 373, 373*f*  
 structure of, 5, 5*f*, 371–374,  
 372*f*, 373*f*  
 survival time in boiling water, 185  
 taxonomy of, 374–375, 377–378*t*  
 viral species and, 375  
 that infect bacteria, 234–235  
 three-domain system and, 281  
 tumor cells naturally infected  
 by, 371  
 vaccines and, 505, 506*f*, 507*t*  
 vaccines and animal cells used to  
 produce, 245  
 viral enzymes and host enzymes, 379  
 virions and, 371  
 VISA (vancomycin-resistant *S.*  
*aureus*), 18, 419*t*, 423*b*, 424*t*  
 visible light. *See* light (visible)  
 vitamin B1 (thiamine), 115*t*  
 vitamin B2 (riboflavin), 2, 115*t*  
 vitamin B6 (pyridoxine), 115*t*  
 vitamin B12 (cobalamin), porins  
 and, 2, 86  
 vitamin B12 (cyanocobalamin), 115*t*



- vitamin C (ascorbic acid), fermentation and, 134t
- vitamin E, 115t
- vitamin K, 2, 115t
- vitamins
- coenzymatic functions of selected, 115t
  - in complex culture media, 163
  - how they cross plasma membrane, 91, 91f
  - microbes used in commercial production of, 245
  - microbiological assays and, 162
  - as organic growth factors, 162
- Voges-Proskauer (V-P) test, 282b, 285f, 286
- volutin, 95
- Volvox* (pond alga), 5f
- vomiting, to expel microbes, 455, 474t
- von Behring, Emil A., 10f, 479
- von Nägeli, Carl, 273
- voriconazole, 566t, 574
- Vorticella*, 353f
- VRE (vancomycin-resistant enterococci), 419t, 569, 583b, 640
- VRSA (vancomycin-resistant *Staphylococcus aureus*), 12, 18, 207, 237, 419t, 423b, 424t, 563
- VSV (vesicular stomatitis virus), 378f, 390f
- vulnerability to disease. *See* susceptibility
- vulva, 745, 750f
- vulvovaginal candidiasis, 341, 759
- W**
- Waksman, Selman A., 13t
- walking pneumonia, 694
- wandering (free) macrophages, 460
- Warren, J. Robin, 13t
- warts (papillomas), 447, 597b, 600
- genital, 430, 757, 758f, 761b
  - imiquimod to treat, 570
  - Papillomavirus* causing, 377t, 387
  - symptoms of, 597b
  - treatments for, 600
- Wassermann test, 513
- waste products, metabolic pathway, 121
- wasting syndrome, caused by *Cyclospora cayetanensis*, 419t
- water
- as a solvent, 34
  - amebae living in, 350–351
  - boiling point, 33
  - in dehydration synthesis, 37, 38f
  - dissociation and, 34, 34f
  - distilled, microbial growth and, 158
  - how it crosses plasma membrane, 91, 92–93
  - hydrogen bond formation in, 31, 31f
  - in hydrolysis, 38f
  - as an inorganic compound, 33–34, 34f
  - microbial growth and, 156
  - mole of, 31
  - molecular weight, 31
  - as nonliving disease reservoirs, 411, 412f, 413
  - polluted, algal blooms and, 348
  - properties, 33–34, 34f
  - protozoa inhabit, 348
  - as reactant or product in chemical reactions, 34
  - recreational, protozoal infections and, 356t, 357b
  - structure, 31f, 33–34
  - as temperature buffer, 34
- water (drinking)
- chloramines to disinfect, 194
  - household bleach to disinfect in emergencies, 194
- water molds (Oomycota), 345t, 347–348, 347f
- as decomposers of dead algae, animals, 344
  - in kingdom Stramenopila, 343
- water molecules, hydrogen bond of, 31, 31f, 33
- water pipes
- bacterial growth in, 97b
  - Burkholderia* form biofilms in, 444b, 689
  - Legionella* and, 309
- water pollution
- bioremediation and, 16, 32b
  - blooms of dinoflagellate species as indicators, 344
  - chemicals, 784–785
  - detergents, 779
  - microbial ecology and, 15
  - pathogenic organisms in, 412, 412f, 784
  - typhoid fever and, 784, 784f
- water quality
- chemicals in, 784–785
  - pathogenic organisms in, 784, 784f
  - purity tests, 785–787, 787f
- water treatment, 788–789, 788f
- chloramines to disinfect, 194
  - chlorine dioxide and, 194, 198
  - disinfection, 788, 788f
  - filtration, 788, 788f
  - flocculation, 788, 788f
  - ozonators, 788, 788f
- waterborne diarrhea
- Cryptosporidium* causing, 357b
  - Cyclospora cayetanensis* causing, 353
- Watson, James D., 10f, 15, 44, 47
- wavelengths of light, algae and, 344–345, 344f
- waxes, 144
- waxy lipid, 433. *See also* mycolic acid
- weapons, microbes as. *See* biological weapons
- weather, infectious disease incidence and, 410
- WEE virus/*Togavirus* (western equine encephalitis), 377t, 634, 634b
- Weil's disease, 747, 754
- Weizmann, Chaim, 2
- Weller, Thomas H., 13t
- West Nile encephalitis (WNE), 19, 220b, 220f, 331f, 377t, 631, 634b
- as an arbovirus, 631, 634b
  - disease reservoirs for, 413t
  - as an emerging infectious disease, 19, 419t
  - as *Flavivirus*, 377t, 628b
  - transmission due to, 413t
  - as zoonotic disease, 413t
- West Nile virus (WNV), 19, 220b, 220f, 378t, 631, 634b
- as an arbovirus, 631
  - birds as disease reservoirs, 19, 220b, 413t, 631, 634b
  - DNA vaccine for horses, 503, 508
  - emerging infectious diseases and, 19, 419t
  - horses protected by vaccine for, 508
  - modern transportation and spread of, 418
  - mosquitos as vectors of, 363f, 365, 631, 634b
  - PCR used to identify, 380
- Western blotting (immunoblotting), 286–287, 288f, 380, 521
- western equine encephalitis (WEE virus/*Togavirus*), 377t, 630, 634b
- whales
- influenza A viruses and, 18, 374b
  - pilot, cetacean morbillivirus (CM) and, 282b
- wheat, food allergies and, 525
- whey, 798
- in cheese production, 798–799, 799f
  - as liquid waste by-product of dairy industry, 801b
  - used for xanthan production, 801b
  - Xanthomonas campestris* used to produce xanthan from, 808b
- Whipple's disease, PCR used to identify cause, 290
- whipworm (*Trichuris trichiura*), 361, 364t, 472, 740b, 742
- white blood cells, 456, 457t. *See also* leukocytes
- White Cliffs of Dover, as fossilized colonies of marine protist, 277
- white rust, 347
- whiteflies, watermelon wilt transmitted by, 396t
- Whitewater Arroyo virus, 666
- Whittaker, Robert H., 273
- WHO. *See* World Health Organization
- whooping cough (pertussis), 306, 687–688, 687f, 706b
- as emerging infectious disease, 419t
  - incubation period, 431t
  - as notifiable infectious disease, 424t
  - portal of entry, 431t
  - spread by droplet transmission, 411–412, 412f
  - vaccine, 14, 506t, 507t, 687
- wildlife management, veterinary microbiologists and, 282b
- Wilkins, Maurice A. F., 47
- wine
- fermentation and, 134b, 134t, 806, 807f
  - souring/spoilage, pasteurization and, 8, 800
  - steps in winemaking, 806, 807f
  - sulfur dioxide as disinfectant, 196, 807f
- Winogradsky, Sergei, 10f, 15
- Wiskott-Aldrich syndrome, 544t
- WNE. *See* West Nile encephalitis
- WNV. *See* West Nile virus
- Woese, Carl R., 6, 10f, 274
- Wolbachia* genus/spp., 300t, 306, 308b, 308f
- as endosymbionts, 300t, 306, 308b, 308f
  - evolutionary implications of, 308b
  - heartworm life cycle and, 362
  - wood-eating termites, 106b
- World Health Organization (WHO)
- disease rankings by, 330
  - global pandemic diseases and, 18
  - priorities for emerging infectious diseases, 418
- worms. *See* helminths
- wound botulism, 624
- wound infection, as portal of exit, 447
- wound tumor virus (plant virus), 396t
- wounds. *See also* surgical wounds
- Acinetobacter* and infections of, 309
  - Bacteroides* and, 322
  - botulism, 618
  - Enterococcus faecalis* and, 317
  - Enterococcus faecium* and, 317
  - genetically modified epidermal growth factor to heal, 259t
  - Proteus* and infections of, 311
  - Pseudomonas* and infections of, 308
  - silver-impregnated dressings and, 195
- Wuchereria bancrofti*, elephantiasis caused by, 446
- X**
- X factor, *Haemophilus* bacteria and, 312
- X-gal (culture medium), 255, 255f
- X-linked infantile (Bruton's) agammaglobulinemia, 544t
- X ray crystallography, 373
- X rays, 189, 190f. *See also* radiation
- as mutagens, 227–228
- xanthan (thickening agent), produced from whey, 801b
- xanthins, 345t
- Xanthomonas campestris*, producing xanthan, 808b
- xanthophylls, 345t
- XDR (extensively drug-resistant) strains of tuberculosis, 691
- xenobiotics, 780–781
- xenografts, 541
- Xenopsylla* (rat flea), as vector, 363f, 364t, 413t, 648
- xenotransplantation products, 541
- xeroderma pigmentosum, 228
- Xgel hand sanitizer, 196
- Xigris (drotrecogin alfa), 646
- XMRV retrovirus, 639
- Xolair (omalizumab), 530
- xTAG respiratory panel, 698
- xylitol, *S. mutans* dental caries and, 135b, 137b
- Y**
- yaws, 447, 759
- yeast extracts, in complex culture media, 163
- yeast infection, 341. *See also* candidiasis
- yeasts, 2, 4, 5f, 280, 333–334, 334f

- budding, 333, 334f
- cell wall of, 98
- as eukaryotes, 6, 75, 330, 331f
- fermentation and, 9. *See also* fermentation
- fission, 333–334
- genetically modified to produce vaccines, 245, 258
- high osmotic pressures and growth of, 189
- living, that are millions of years old, 277
- peroxidase production and, 3b
- pH and growth of, 156
- rapid identification tests for, 285
- reproduction in, 304, 333–334, 334f
- as workhorse of biotechnology, 256, 258
- yellow fever, 364t, 377t, 414t, 447, 667, 667b
  - filterable agents and, 369
  - mosquito as vector, 363f, 364t, 414t, 667, 667b
  - as notifiable infectious disease, 424t
  - as potential biological weapon, 654b
  - vaccine, 505, 667
- Yersinia enterocolitica*, 282b, 726
- Yersinia gastroenteritis* (yersiniosis), 726, 728b
- Yersinia* genus/spp., 301t, 311
- Yersinia pestis*
  - as a biological weapon, 654b
  - capsule of, virulence and, 433
  - plague caused by, 311. *See also* plague
  - portals of entry, 431
  - reservoirs/transmission method, 413t
- Yersinia pseudotuberculosis*, 726
- yersiniosis (*Yersinia gastroenteritis*), 726, 728b
- yew trees, Taxol and, 341
- yogurt
  - fermentation and, 134t
  - microbes used to make, 799
  - pasteurization time/temperature and, 187
- Yonath, Ada E., 13t
- Z**
- zanamivir (Relenza), 566t, 575, 701
- Zephiran (benzalkonium chloride), 195, 196, 196f, 198b, 202t
  - Zephiran-soaked cotton balls, *M. abscessus* infection and, 198b
- zidovudine, 575
- zimatadine, 566t
- zinc
  - as antimicrobial agent, 196
  - as cofactor, 115
- zinc chloride, 196
- zinc pyrithione, 196
- Zinkernagel, Rolf. M., 13t
- zippers, made by microbes, 3b
- zone of inhibition, 578, 578f
- Zoogloea* genus/spp., 301t, 307
  - in sewage treatment, 301t, 307, 784, 786f
- zoonoses/zoonosis, 411, 413t, 648, 649
- zoospores, 347, 347f
- zoster vaccine, 602
- zur Hausen, Harald, 13t
- zygomycetes, 336f
- Zygomycota, 336f, 337, 340t
- zygosporangium, 336f
- zygospore, 336f, 337
- zygote
  - in apicomplexan reproduction, 349, 352f
  - in life cycle of *Rhizopus*, 336f
- Zyvox (linezolid), 565t, 572





# BRIEF CONTENTS

## PART ONE Fundamentals of Microbiology

1	The Microbial World and You	1
2	Chemical Principles	25
3	Observing Microorganisms Through a Microscope	53
4	Functional Anatomy of Prokaryotic and Eukaryotic Cells	75
5	Microbial Metabolism	111
6	Microbial Growth	153
7	The Control of Microbial Growth	181
8	Microbial Genetics	207
9	Biotechnology and DNA Technology	244

## PART TWO A Survey of the Microbial World

10	Classification of Microorganisms	272
11	The Prokaryotes: Domains Bacteria and Archaea	299
12	The Eukaryotes: Fungi, Algae, Protozoa, and Helminths	330
13	Viruses, Viroids, and Prions	369

## PART THREE Interaction Between Microbe and Host

14	Principles of Disease and Epidemiology	401
15	Microbial Mechanisms of Pathogenicity	429
16	Innate Immunity: Nonspecific Defenses of the Host	451
17	Adaptive Immunity: Specific Defenses of the Host	478
18	Practical Applications of Immunology	504
19	Disorders Associated with the Immune System	527
20	Antimicrobial Drugs	558

## PART FOUR Microorganisms and Human Disease

21	Microbial Diseases of the Skin and Eyes	589
22	Microbial Diseases of the Nervous System	615

23	Microbial Diseases of the Cardiovascular and Lymphatic Systems	643
24	Microbial Diseases of the Respiratory System	680
25	Microbial Diseases of the Digestive System	711
26	Microbial Diseases of the Urinary and Reproductive Systems	749

## PART FIVE Environmental and Applied Microbiology

27	Environmental Microbiology	772
28	Applied and Industrial Microbiology	799

Answers to Review and Multiple Choice Study Questions		AN-1
---	--	------

Appendix A	Metabolic Pathways	AP-1
------------	--------------------	------

Appendix B	Exponents, Exponential Notation, Logarithms, and Generation Time	AP-7
------------	--	------

Appendix C	Methods for Taking Clinical Samples	AP-8
------------	-------------------------------------	------

Appendix D	Pronunciation of Scientific Names	AP-9
------------	-----------------------------------	------

Appendix E	Word Roots Used in Microbiology	AP-13
------------	---------------------------------	-------

Appendix F	Classification of Prokaryotes According to <i>Bergey's Manual</i>	AP-16
------------	---	-------

Glossary	G-1
----------	-----

Credits	C-1
---------	-----

Index	I-1
-------	-----





*See the connection between*

**HUMAN HEALTH &  
MICROBIOLOGY**

# TAXONOMIC GUIDE TO DISEASES

## Bacteria and the Diseases They Cause

### Alphaproteobacteria

Anaplasmosis	<i>Anaplasma phagocytophilum</i>	p. 660
Brucellosis	<i>Brucella</i> spp.	pp. 649–650
Cat-scratch disease	<i>Bartonella henselae</i>	pp. 653–654
Ehrlichiosis	<i>Ehrlichia</i> spp.	p. 660
Endemic murine typhus	<i>Rickettsia typhi</i>	pp. 660–661
Epidemic typhus	<i>R. prowazekii</i>	p. 660
Rocky Mountain spotted fever	<i>R. rickettsii</i>	pp. 661–662

### Betaproteobacteria

Gonorrhea	<i>Neisseria gonorrhoeae</i>	pp. 754–756, 757
Melioidosis	<i>Burkholderia pseudomallei</i>	p. 697
Meningitis	<i>N. meningitides</i>	pp. 618–619
Nosocomial infections	<i>Burkholderia</i> spp.	p. 430
Ophthalmia neonatorum	<i>N. gonorrhoeae</i>	pp. 610, 755
Pelvic inflammatory disease	<i>N. gonorrhoeae</i>	p. 758
Rat-bite fever	<i>Spirillum minor</i>	pp. 654–655
Whooping cough	<i>Bordetella pertussis</i>	pp. 505, 687–688

### Gammaproteobacteria

Animal bites	<i>Pasteurella multocida</i>	p. 653
Bacillary dysentery	<i>Shigella</i> spp.	pp. 718–719
Chancroid	<i>Haemophilus ducreyi</i>	p. 762
Cholera	<i>Vibrio cholerae</i>	pp. 722–723, 773
Conjunctivitis	<i>H. influenzae</i>	pp. 609–610
Conjunctivitis	<i>Pseudomonas aeruginosa</i>	p. 559
Cystitis	<i>Escherichia coli</i>	p. 752
Dermatitis	<i>P. aeruginosa</i>	pp. 590, 596
Epiglottitis	<i>H. influenzae</i>	p. 683
Gastroenteritis	<i>E. coli</i>	pp. 712, 723–724
Gastroenteritis	<i>V. parahaemolyticus</i>	p. 723
Gastroenteritis	<i>V. vulnificus</i>	p. 723
Gastroenteritis	<i>Yersinia enterocolitica</i>	p. 726
Gastroenteritis	<i>Y. pseudotuberculosis</i>	p. 726
Legionellosis	<i>Legionella pneumophila</i>	pp. 694, 698
Meningitis	<i>H. influenzae</i>	p. 618
Otitis externa	<i>P. aeruginosa</i>	p. 598
Otitis media	<i>H. influenzae</i>	p. 685
Otitis media	<i>Moraxella catarrhalis</i>	p. 685
Plague	<i>Y. pestis</i>	pp. 655–658
Pneumonia	<i>H. influenzae</i>	p. 691
Pneumonia	<i>Klebsiella pneumoniae</i>	pp. 76, 311
Pyelonephritis	<i>E. coli</i>	p. 752
Q fever	<i>Coxiella burnetii</i>	pp. 696–697
Salmonellosis	<i>Salmonella enterica</i>	pp. 273, 719–720, 721, 800
Septicemia	<i>P. fluorescens</i>	pp. 154, 646
Tularemia	<i>Francisella tularensis</i>	pp. 648–649, 651
Typhoid fever	<i>S. typhi</i>	pp. 720–723

### Epsilonproteobacteria

Gastritis, peptic ulcers	<i>Helicobacter pylori</i>	pp. 725–726
Gastroenteritis	<i>Campylobacter jejuni</i>	p. 724

### Clostridia

Botulism	<i>Clostridium botulinum</i>	pp. 622–625
Gangrene	<i>C. perfringens</i>	pp. 652–653

# TAXONOMIC GUIDE TO DISEASES (continued)

## Clostridia (continued)

Gastroenteritis	<i>C. difficile</i>	pp. 402, 726
Gastroenteritis	<i>C. perfringens</i>	p. 726
Tetanus	<i>C. tetani</i>	pp. 621–622

## Mollicutes

Pneumonia	<i>Mycoplasma pneumoniae</i>	pp. 691–692
Urethritis	<i>Mycoplasma, Ureaplasma</i>	p. 758

## Bacilli

Anthrax	<i>Bacillus anthracis</i>	pp. 26, 650–652
Bacterial endocarditis	<i>Staphylococcus aureus</i>	p. 648
Cystitis	<i>S. saprophyticus</i>	p. 752
Dental caries	<i>Streptococcus mutans</i>	pp. 112, 713–715
Endocarditis	Alpha-hemolytic streptococci	pp. 647–648
Erysipelas	<i>Streptococcus pyogenes</i>	p. 595
Folliculitis	<i>Staphylococcus aureus</i>	p. 593
Food poisoning	<i>Staphylococcus aureus</i>	pp. 717–718
Gastroenteritis	<i>B. cereus</i>	pp. 726–727
Impetigo	<i>S. aureus</i>	p. 593
Listeriosis	<i>Listeria monocytogenes</i>	pp. 619–621
Meningitis	<i>Streptococcus agalactiae</i>	p. 300
Meningitis	<i>Streptococcus pneumoniae</i>	p. 619
MRSA infections	<i>Staphylococcus aureus</i>	pp. 423, 593, 598
Necrotizing fasciitis	<i>Streptococcus pyogenes</i>	p. 575
Otitis media	<i>S. pneumoniae</i>	p. 685
Pneumonia	<i>S. pneumoniae</i>	p. 691
Puerperal sepsis	<i>S. pyogenes</i>	p. 646
Rheumatic fever	<i>S. pyogenes</i>	p. 648
Scalded skin syndrome	<i>Staphylococcus aureus</i>	p. 593
Scarlet fever	<i>Streptococcus pyogenes</i>	p. 683
Sepsis	<i>Enterococcus</i> spp.	pp. 646–647
Sepsis	<i>Streptococcus agalactiae</i>	p. 647
Strep throat	<i>S. pyogenes</i>	p. 683
Toxic shock syndrome	<i>Staphylococcus aureus</i>	p. 594
Toxic shock syndrome	<i>Streptococcus pyogenes</i>	p. 595

## Actinobacteria

Abscess	<i>Mycobacterium abscessus</i>	p. 198
Acne	<i>Propionibacterium acnes</i>	pp. 599–600
Buruli ulcer	<i>M. ulcerans</i>	p. 599
Diphtheria	<i>Corynebacterium diphtheriae</i>	pp. 684–685
Leprosy	<i>M. leprae</i>	pp. 625–626
Mycetoma	<i>Nocardia asteroides</i>	p. 320
Tuberculosis	<i>M. tuberculosis</i>	pp. 688–691
Tuberculosis	<i>M. bovis</i>	p. 142
Vaginosis	<i>Gardnerella vaginalis</i>	p. 762

## Chlamydiae

Inclusion conjunctivitis	<i>Chlamydia trachomatis</i>	p. 610
Lymphogranuloma venereum	<i>C. trachomatis</i>	p. 762
Pelvic inflammatory disease	<i>C. trachomatis</i>	p. 758
Pneumonia	<i>Chlamydophila pneumoniae</i>	p. 696
Psittacosis	<i>C. psittaci</i>	pp. 681, 694–696
Trachoma	<i>Chlamydia trachomatis</i>	p. 610
Urethritis	<i>C. trachomatis</i>	pp. 757–758



# TAXONOMIC GUIDE TO DISEASES (continued)

## Spirochetes

Leptospirosis	<i>Leptospira interrogans</i>	pp. 750, 752–754
Lyme disease	<i>Borrelia burgdorferi</i>	pp. 658–660
Relapsing fever	<i>Borrelia</i> spp.	p. 658
Syphilis	<i>Treponema pallidum</i>	pp. 758–762

## Bacteroidetes

Acute necrotizing gingivitis	<i>Prevotella intermedia</i>	p. 716
Periodontal disease	<i>Porphyromonas</i> spp.	pp. 715–716
Septic shock	<i>Capnocytophaga canimorsus</i>	p. 479

## Fusobacteria

Rat-bite fever	<i>Streptobacillus moniliformis</i>	pp. 654–655
----------------	-------------------------------------	-------------

## Fungi and the Diseases They Cause

### Zygomycetes

Opportunistic infections	<i>Mucor</i> , <i>Rhizopus</i>	p. 704
--------------------------	--------------------------------	--------

### Microsporidia

Opportunistic infections	<i>Encephalitozoon intestinalis</i>	p. 337
--------------------------	-------------------------------------	--------

### Ascomycetes

Aspergillosis	<i>Aspergillus fumigatus</i>	pp. 452, 704
Blastomycosis	<i>Blastomyces dermatitidis</i>	p. 704
Candidiasis	<i>Candida albicans</i>	pp. 762, 765–766, 606
Coccidioidomycosis	<i>Coccidioides immitis</i>	p. 703
Histoplasmosis	<i>Histoplasma capsulatum</i>	pp. 702–703
Pneumonia	<i>Pneumocystis jirovecii</i>	pp. 703–704
Ringworm, Athlete's foot	<i>Microsporum</i> , <i>Trichophyton</i>	pp. 605–606
Sporotrichosis	<i>Sporothrix schenckii</i>	p. 606

### Basidiomycetes

Dandruff	<i>Malassezia furfur</i>	p. 591
Meningitis	<i>Cryptococcus</i> spp.	pp. 332, 632–633
Mycotoxins		pp. 445, 735

## Protozoa and the Diseases They Cause

### Diplomonads

Giardiasis	<i>Giardia lamblia</i>	p. 591
------------	------------------------	--------

### Parabasilids

Trichomoniasis	<i>Trichomonas vaginalis</i>	pp. 762, 766–768
----------------	------------------------------	------------------

### Euglenozoa

African trypanosomiasis	<i>Trypanosoma brucei</i>	p. 633
Chagas' disease	<i>T. cruzi</i>	pp. 666–668
Leishmaniasis	<i>Leishmania</i> spp.	pp. 672–673
Meningoencephalitis	<i>Naegleria fowleri</i>	pp. 633–635, 616

### Apicomplexa

Babesiosis	<i>Babesia microti</i>	p. 673
Cryptosporidiosis	<i>Cryptosporidium</i> spp.	pp. 357, 737
<i>Cyclospora</i> infection	<i>Cyclospora cayetanensis</i>	pp. 737–738
Malaria	<i>Plasmodium</i> spp.	pp. 668–672
Toxoplasmosis	<i>Toxoplasma gondii</i>	p. 668